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ENERGY FACTORS AND TEMPERATURE DISTRIBUTION IN INSULATED BUILT---ETC(U)
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author: John R. Keeton and Robert L. Alumbaugh, Ph D

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Surface temperatures of 4-ply built-up roofs insulated with (1) 1 inch of perlite (R = 2.8) and 2-1/2 inches of urethane (R = 19.2) and (2) 1 inch of urethane (R = 7.1) and 1-7/8 inches of glass fiber (R = 7.7) are presented. Energy factors are shown in terms of temperature-time areas defined as solar heat response, cooling (heating) required, radiative cooling, and insulation efficiency. Results indicate that for a black surface, solar heat

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response is significantly higher in the roof portion with the higher R-value. Solar heat response is directly affected by color of surfacing; lowest to highest values were found with white, white gravel, gray gravel, aluminum-gray, and black. Recommendations are given for reducing surface temperatures of insulated built-up roofs.

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INTRODUCTION

For many years built-up roofs (BUR) were constructed with little or no insulation. When building owner and architect agreed that some insulation was desirable, it often amounted to a layer of mineral fiberboard or perlite board from 1/2 to 1 inch thick. In the days of ample energy for heating and cooling and of seemingly endless supplies of crude oil, this meager provision for energy conservation seemed reasonable.

As prices for energy began to rise and fuel shortages began to appear in the mid-1960s, manufacturers of roofing materials along with chemical manufacturers began to develop and produce more exotic insulations, such as cellular plastics (urethane foam and polystyrene foam) and glass fiber. By the mid-1970s, all government agencies began to document energy conservation requirements. The Department of Defense (DOD) Construction Criteria Manual 4270.1M of October 1972 required an overall coefficient of heat transmission (U) of 0.05 Btu/ hr/ft^2/°F (R = 20) for roofs. It was realized that rather large heat losses through roofs could be vastly reduced with adequate insulation.

Since by far the vast majority of roofs are built-up, most of the applications of thicker insulation have been in these roofs. There has been serious concern in the roofing industry that thicker insulation (higher thermal resistance) in a built-up roof may cause extremely high membrane temperatures which could severely shorten the service life of the roof by accelerating deterioration of the asphalt ingredients (premature loss of volatile components, hardening, and cracking of the asphalt) (Ref 1 through 3). In a National Bureau of Standards report published in 1976, Rossiter and Mathey maintained that built-up roof temperatures increase substantially as insulation thickness is increased up to 1 inch, but that insulation thicker than 1 inch will not add significantly to the built-up temperatures (Ref 4).

To investigate the effects of higher insulation thicknesses (high thermal resistance) upon temperatures in built-up roofs, the Civil Engineering Laboratory (CEL) began a research study which has involved construction and instrumentation of insulated built-up roofs placed on small, temperature-controlled buildings.

EXPERIMENTAL PROGRAM

Insulated temperature-controlled buildings (ITCB) were designed and built to accommodate a roof size of 8 x 8 feet. Each 8 x 8-foot roof consisted of two 4 x 8-foot sections to provide for two different hot-mopped, 4-ply built-up membranes placed over 3/4-inch plywood. Asbestos felts were used in construction of the 4-ply built-up membranes. Temperature inside the ITCB was controlled in summer by an air conditioner (72-78°F) and in winter by an electric heater (65-70°F). The outside walls were sprayed with at least 3 inches of polyurethane foam (PUF), and PUF board stock 2 inches thick was used in the floor. One of the ITCBs is shown in Figure 1. Composition of the ITCB roofs and their location are presented in Table 1.

The plans for the three different ITCB roofs are shown in Figure 2. The circled Ts indicate positions of thermocouples used to measure temperatures in and through the roof sections. During construction of the built-up roofs, thermocouples were placed (1) on top of the membrane (below top coating or surfacing), (2) below the membrane (on top of the insulation), (3) below the insulation (on the plywood), and (4) inside the ITCB. The outside air temperature above the roof was also measured (about 3 feet above the roof). Hourly temperatures were automatically recorded on a digital printout instrument.

TEST RESULTS - SUMMER

ITCB No. 1: 2-1/2 Inches Urethane/1 Inch Perlite - Black Roof Surface

ITCB No. 1 was designed to provide a side-by-side comparison of surface temperatures and temperature distribution between a highly insulated section which substantially meets current energy criteria (2-½ inches of urethane board stock) and one which is representative of past usage (1 inch of perlite board stock). As indicated in Table 1, this roof provided contrasting thermal resistance (R) values of 19.2 (urethane) and 2.8 (perlite). Top surfacings of the two built-up roof sections were (1) a flood coat of black asphalt or (2) white gravel (placed in a flood coat of asphalt). This ITCB was located at a high desert site that is subject to extremely high temperatures in summer and to moderate freezing temperatures in winter.

Hourly temperature data are listed in Table 2 for June 7-8, 1978. Column 1 lists the time of day, while columns 2 and 3 show the temperatures at the top of the built-up roof with a black surface over urethane and perlite, respectively. Columns 4 and 5 show the same relationships for the membrane with a white gravel surface. Columns 6, 7, 8, and 9 indicate the same data just below the membrane, or on top of the insulation. Columns 10, 11, 12, and 13 show temperatures just below the insulation, reflecting the relative effectiveness of the insulation to inhibit heat flow. Columns 14 and 15 register inside and outside air temperatures, respectively.

Although columns 2 and 3 for both days show temperature differences up to 20 degrees at the hottest time of the day at the top of the roof, a more realistic comparison would include the entire built-up roof membrane (i.e., an average of columns 2 and 6 for the membrane over urethane and an average of columns 3 and 7 for the membrane over perlite). Figure 3 shows all of the temperatures involving the built-up roof with a black surface, using averages of "Top of BUR" and "Top of Insulation" to obtain membrane temperatures. Considering first the membrane temperatures over urethane and perlite (open circles and open squares), the differences at the higher temperatures may not seem significant. Some provocative energy relationships are revealed, however, when the total time-temperature "envelope" is considered. This time-temperature envelope is obtained by measuring the area under each of the curves with respect to selected datum lines. An example is given in simplified form in Figure 4 which repeats the June 7, 1978 temperature data for the urethane portion of Figure 3 (columns 2, 6, 10, and 15 of Table 2).

Assuming that the temperatures that a roof experiences result from exposure to the sun, then the outside air temperature is a measure of the intensity of the sun for a given day, influenced directly by clouds and wind speed. Accordingly then, the area ABCDA in Figure 4 can be called a measure of the "solar heat response," since this area represents how much the membrane temperature exceeds the outside air temperature (plus signs) during the daytime hours of highest solar intensity (i.e., between 0800 and 1900).

The solid circles in Figure 4 are the temperatures below the urethane. Assuming that 75°F is a reasonable room temperature for summer and drawing a horizontal line at that temperature, then the area EFGE represents a measure of the "cooling required" for the hotter portion of that day.

In early morning and late evening the membrane temperatures (open circles) drop below the outside air temperatures (plus signs) primarily by radiative cooling. Accordingly, the areas HJAH and LCKL represent a measure of the "radiative cooling" for that day.

Examination of columns 6 and 10 of Table 2 indicates that the temperature of the membrane increases more rapidly than the temperature below the insulation, due to the very nature and function of the insulation (nonsteady state). It is this time delay between the instant of highest temperature above and reaction to that temperature below that makes it very difficult to determine a true instantaneous temperature-drop across the insulation. Nevertheless, the area MBNFM between the membrane temperature (open circles) and the temperature below the insulation (closed circles) can be used as a measure of the "insulation efficiency" relative to a similarly measured area between the corresponding two curves involving a different insulation on the same roof. In winter, insulation efficiency is determined by measuring the areas between membrane and below insulation temperatures in the early and late daily hours (e.g., HVMH and LNWL).

Outside air temperatures over the entire day not only indicate relative heat or sun intensity, but also reflect the effects of cloud cover, wind speed, and radiation from the membrane during early morning and late night hours. Measurement of the area under the outside temperatures (plus signs) with respect to a datum temperature of 0°F then represents a measure of the overall temperature severity of that day. Referring to Figure 4, the area PJDKRP is the area for June 7, 1978 referred to 40°F; the area between 40°F and 0°F must be added to obtain the total outside air temperature area for that day. Similarly, the outside temperature area for the hottest portion of the day (0800-1900) may be obtained by measuring the area STDCUS and adding to it the area from 40°F to 0°F for 0800 to 1900.

All hourly temperatures for each day were plotted on 20 x 20 rectangular grid graph paper, and areas were measured with a compensating polar planimeter that reads to four digits. One square inch measured 100. Each area was measured three times to minimize errors and to obtain an average.

Relative energy factors and selected temperatures for the black surface portion of the roof on ITCB No. 1 are shown in Table 3 for selected days in late spring, summer, and early fall of 1977 and 1978.

Solar Heat Response. Columns 14 and 15 of Table 3(a) show the highest membrane temperatures on the built-up roof membrane with a black surface during each day and column 16 lists the ratio of the temperature over the urethane to the temperature over the perlite. Temperature over the urethane was consistently higher and the ratio averaged 1.09 (i.e., membrane temperatures over the urethane averaged 9% higher than over the perlite). Columns 2 and 3 show areas for solar heat response and column 4 indicates the ratio of the urethane portion to the perlite portion. Values for the urethane portion were consistently higher and the ratios averaged 1.29. This means that in spite of what appears to be an insignificant difference (9%) on the basis of highest membrane temperature alone, the solar heat response of the built-up roof membrane over urethane (R = 19.2) was an average of 29% more than that over the perlite (R = 2.8). Variations of solar heat response values in columns 2 and 3 reflect differing degrees of solar intensity influenced by cloud cover and/or wind speed. Since solar heat response is measured during the hotter portion of the daytime, the data in Table 3(a) are listed in decreasing order of solar intensity in terms of outside air temperature areas for the period 0800-1900 (column 21).

Graphical relationships between solar heat response and outside temperature area (0800-1900) for the black surface membrane over urethane and over perlite are shown in Figure 5(a) and (b), respectively. Lines shown are least squares lines. Figure 5(c) illustrates the relationships between the two least squares lines, showing that solar heat response over the urethane is consistently higher and increases more rapidly as the heat intensity increases (to the right).

Cooling Required. Columns 5 and 6 of Table 3(a) show cooling required and column 7 lists the ratio of the urethane to perlite portions. As expected, considerably more cooling is required in the perlite portion due to the lower R-value. Variations in columns 5 and 6 also reflect effects of differing solar intensity from day to day. Ratios in column 7 show a trend toward lower values as the heat intensity decreases (i.e., toward the bottom of the table). Lines 23 through 26, days with the lowest heat intensity (column 21), show the lowest ratios. This seems to indicate that the urethane insulates more efficiently at lower heat intensities. This is consistent with available data which show that the apparent conductivity of polyurethane foam is higher at 100°F than at 60°F (Ref 5). More about this is discussed later in this report. The average ratio in column 7 is 0.37, which means that the perlite portion (R = 2.8) requires an average of 1 ÷ 0.37 = 2.70 times as much cooling as the urethane portion (R = 19.2). Note that the ratio between R-values is 6.86; there may be an optimum economic thickness of insulation (or R-value). Graphically, Figure 6 shows cooling required for both urethane and perlite portions.

Radiative Cooling. Columns 8 and 9 of Table 3(a) list radiative cooling values and column 10 shows the ratio of urethane to perlite. Values over the urethane are consistently higher than over the perlite but there are significant variations caused by the degree to which the evening and night sky was clear or cloudy. Ratios in column 10 average 1.28, suggesting that the built-up roof membrane over the urethane (R = 19.2) radiates an average of 28% more than that over the perlite (R = 2.8). Figure 7(a) and (b) show graphical relationships between radiative cooling and the outside temperature area from 0000 to 2400 (column 22 of Table 3(a)) for urethane and perlite portions, respectively. In both cases, the trend seems to be toward lower values at the extremities of hotter and cooler days (curving down at left and right ends). As indicated in Figure 7(c), least squares lines for the two show that radiative cooling is higher in the urethane portion.

Insulation Efficiency. Columns 11 and 12 of Table 3(a) show insulation efficiency values and column 13 lists the ratios of urethane to perlite. As expected, the efficiency of the urethane (R = 19.2) is consistently higher than the perlite (R = 2.8). Ratios average 1.53, suggesting that the efficiency of the urethane is an average of only 53% higher than that of the perlite, the rather significant R-value ratio of 6.86 between them notwithstanding. As before, these results suggest that there may be an optimum economical R-value for insulation in a roof of this type. Figure 8 shows the graphical relationships between the insulation efficiencies.

ITCB No. 1: 2-1/2 Inches Urethane/1 Inch Perlite - White Gravel Roof Surface

Figure 9 is a typical plot of temperatures involving a white gravel roof surface for August 1-2, 1977. Figure 9 shows that differences between membrane temperatures over urethane and perlite are slight compared with those in Figure 3. Table 3(b) is a summary of energy factors for the white gravel surface, tabulated in decreasing order of heat intensity as with Table 3(a). Columns 14 and 15 of Table 3(b) show considerably lower temperatures than the corresponding temperatures in Table 3(a), because the white gravel absorbs much less heat than the black surface.

Solar Heat Response. Columns 2 and 3 of Table 3(b) show only slight differences between solar heat response of urethane and perlite portions. The higher value alternates between the two throughout the tabulation. As indicated in column 4, the average ratio of urethane to perlite is 1.02, which is considerably less than the corresponding average ratio of 1.29 found in Table 3(a) for a black-surfaced membrane. The average ratio of 1.02 is the same as the average highest membrane temperature ratio of 1.02, shown in column 16 of Table 3(b). Further comparisons can be made between Tables 3(b) and (a) by referring to lines (or days) of equal heat intensity, such as 1 and 1, 2 and 2, 3 and 5, 4 and 6, 5 and 7, and so on.

Graphical relationships of solar heat absorption for urethane and perlite portions are presented in Figure 10(a) and (b), respectively. The effects of roof surfacing on solar heat absorption for ITCB No. 1 are shown in Figure 11. White gravel surfacing is much less sensitive to solar heat than is the black. The color contrast between black and white is the significant factor involved.

Cooling Required. Columns 5 and 6 of Table 3(b) indicate, as expected, that more cooling is required in the perlite portion. Wide variations noted in the values are also reflected in the ratios in column 7. There seems to be a trend toward lower ratios as the heat intensity decreases (i.e., toward the bottom of the table). The average ratio is 0.37, which is the same as the average ratio shown in column 7 of Table 3(a) for the black surface. Graphical relationships of cooling required for a white gravel surface over urethane and perlite are shown in Figure 12(a). Comparisons between black surface and white gravel surface data over urethane and over perlite are shown in Figure 12(b) and (c), respectively. Least squares lines in Figure 12(b) are almost parallel, whereas the lines in Figure 12(c) diverge at the higher heat intensities (right side of graph), with the black over perlite showing more sensitivity to heat than the white gravel over perlite.

Radiative Cooling. Columns 8 and 9 of Table 3(b) show significantly higher values for the urethane portion. Ratios in column 10 average 1.31, which is only slightly different from the corresponding ratio in column 10 of Table 3(a). Figure 13(a) and (b) present graphical relationships between radiative cooling and the outside temperature area (column 22 of Table 3(b)) for urethane and perlite portions, respectively. Figure 13(c) shows both least squares lines.

Insulation Efficiency. As expected, columns 11 and 12 of Table 3(b) show that insulation efficiency of the urethane portion is consistently higher than over the perlite. The average ratio of 1.24 shown in column 13 is somewhat less than the corresponding ratio (1.53) in column 13 of Table 3(a), revealing that the advantage of the urethane portion is dramatically reduced by the surfacing change from black to white gravel. Insulation efficiencies for the urethane and perlite portions with a white gravel surface are presented in Figure 14(a) and (b), respectively. Figure 14(c) shows that the urethane portion is more efficient than the perlite.

ITCB No. 2: 2-1/2 Inches Urethane/1 Inch Perlite - White Roof Surface

As indicated in Table 1, this roof also provided contrasting R-values of 19.2 (urethane) and 2.8 (perlite). As shown in Figure 2, top surfacing was (1) white, (2) aluminum gray, or (3) gray gravel. ITCB No. 2 was placed in the same high desert location as ITCB No. 1.

A typical temperature plot for the portion with a white surface is presented in Figure 15 for August 7-8, 1978, days of relatively high heat intensity. Relative energy factors are shown in Table 4(a). Highest membrane temperatures in columns 14 and 15 show little differences, although that over the urethane was always higher. The ratio between the two averaged 1.02, as shown in column 16.

Solar Heat Response. Columns 2 and 3 of Table 4(a) show consistently higher values for the urethane portion. At the higher heat intensities (top lines of the table), column 4 shows higher ratios and the ratios decrease as the heat intensity decreases (i.e., lines 7 though 14 of the table). The ratio in line 13 seems to be an exception. The average solar heat response ratio is 1.41 which means that even with white surfacing, the solar heat response of the urethane portion is an average of 41% higher than that in the perlite portion. During the hotter days, as in lines 1 through 6, the average ratio would be 1.63. It should be noted that the order of magnitude of the solar heat response values in columns 2 and 3 of Table 4(a) is much lower than those in both Table 3(a) and (b).

Cooling Required. As expected, columns 5 and 6 of Table 4(a) show consistently more cooling required in the perlite portion. Ratios of urethane to perlite in column 7 are fairly consistent through line 10 (hotter days), but lines 11 through 14 (less heat intensity) show dramatic decreases in ratios. This seems to indicate either that the perlite (R = 2.8) is less efficient as the summer heat begins to cool or that the relative efficiency of the urethane (R = 19.2) increases as the heat intensity reduces. Overall average ratio is 0.22, which means that the perlite portion required an average of 4.54 (1 ÷ 0.22) times as much cooling as the urethane portion over a rather wide range of heat intensities.

Figure 16 shows graphical relationships of cooling required for urethane and perlite portions. The urethane portion (lower curve) is much less sensitive to higher heat intensities. The increasing divergence of the curves as heat intensity increases (to the right) also illustrates the superior efficiency of the urethane portion with higher thermal resistance.

Radiative Cooling. Radiative cooling values are shown in columns 8 and 9 of Table 4(a). In lines 1 through 6 (higher heat intensities) the higher of the two is first in the perlite portion and then in the urethane portion. In lines 7 through 14 the urethane values are consistently higher. As indicated in column 10, the average ratio of urethane to perlite is 1.04. Graphical representations of radiative cooling for urethane and perlite portions are shown in Figure 17(a) and (b), respectively. As noted before, the curves turn down at the extremities of heat intensity. Figure 17(c) shows that radiative cooling over urethane is slightly higher than over perlite.

Insulation Efficiency. Columns 11 and 12 of Table 4(a) show consistently higher values of insulation efficiency for the urethane portion, as expected. Ratios in column 13 are fairly uniform and average 1.55, which suggests that the insulation efficiency in the urethane portion is an average of 55% higher than in the perlite portion. Graphical relationships between the urethane and perlite portions are shown in Figure 18. Convergence of the lines as heat intensity decreases (lower outside temperature area) reveals that for some climatic condition between summer and winter, the insulation efficiency would be the same for the two. Winter relationships are discussed later in this report.

ITCB No. 2: 2-1/2 Inches Urethane/1 Inch Perlite - Aluminum Gray Roof Surface

Figure 19 is a temperature plot of the aluminum gray surface portion of ITCB No. 2 for August 7-8, 1978, two days of very high heat intensity.

Solar Heat Response. Columns 2 and 3 of Table 4(b) show consistently higher values for the urethane portion, and the ratios in column 4 average 1.22. Highest membrane temperatures in columns 14 and 15 also show that temperatures over the urethane are consistently higher than over the perlite, but ratios in column 16 average only 1.05, compared with 1.22 (column 4) for solar heat response. Figure 20(a) and (b) show least squares lines for solar heat response over urethane and over perlite, respectively. As indicated in Figure 20(c), the two lines diverge as the heat intensity increases (to the right), showing that the solar heat response over the urethane increases faster than it does over the perlite.

Cooling Required. Columns 5 and 6 of Table 4(b) show consistently higher cooling required in the perlite portion, as expected. Ratios in column 7 average 0.31. Figure 21 shows graphical relationships for cooling required. Divergence of the least squares lines as heat intensity increases (to the right) indicates greater sensitivity of the perlite portion to heat, as expected.

Radiative Cooling. Columns 8 and 9 of Table 4(b) show that during the hotter days, lines 1 through 11, radiation is higher in the membrane over the perlite than it is over the urethane. The opposite is true in lines 12 through 18, the less heat intensive days in the table. Column 10 shows the ratios which average 1.00. Figure 22(a) and (b) present graphical relationships of radiative cooling for the membrane portions over urethane and perlite, respectively. The least squares curves are similar to those in Figure 7, showing that radiation decreases sharply as the heat intensity decreases. Figure 22(c) shows radiation curves for both urethane and perlite portions. Radiative cooling is higher in the perlite portion during the hottest days.

Insulation Efficiency. As shown in columns 11 and 12 of Table 4(b), efficiency of the urethane is significantly higher than the perlite, as expected. Ratios in column 13 average 1.59, which means that the urethane (R = 19.2) is an average of 59% more efficient than the perlite (R = 2.8). Figure 23 shows least squares lines of insulation efficiency for both urethane and perlite. Efficiency of the urethane increases more rapidly than that of the perlite as heat intensity increases.

ITCB No. 2: 2-1/2 Inches Urethane/1 Inch Perlite - Gray Gravel Roof Surface

Figure 24 is a plot of the temperatures of the gray gravel surface portion of ITCB No. 2 for August 7-8, 1978. As in all the other plots, membrane temperatures over the urethane are higher than those over the perlite in the hotter part of the day. Table 4(c) summarizes the relative energy factors.

Solar Heat Response. Columns 2 and 3 of Table 4(c) show that except for the last line (18) which was a day of relatively low heat intensity (column 21), the urethane portion experienced more solar heat than did the perlite portion. The overall average ratio in column 4 is 1.15, which means that the urethane portion contained an average of 15% more solar heat than the perlite portion. Solar heat response over urethane and perlite is shown in Figure 25(a) and (b), respectively. In Figure 25(c), which shows both least squares lines, the steeper slope of the line over the urethane indicates more sensitivity to solar heat at the higher heat intensities. Figure 26(a) and (b) present least squares lines of solar heat response for all surfaces of ITCB No. 2 over urethane and perlite, respectively. The influence of the white color in reducing solar heat response is quite dramatic.

Cooling Required. Columns 5 and 6 of Table 4(c) show that in all cases more cooling is required in the perlite portion. Ratios in column 7 are fairly uniform except for lines 17 and 18, days of lowest heat intensity. The overall average ratio is 0.21; excluding lines 17 and 18, the average ratio is 0.23, which means that for 16 of the days selected, the perlite portion required 4.35 (1 ÷ 0.23) times as much cooling as the urethane portion. As indicated in Figure 27, cooling required in the urethane portion is much less sensitive to heat intensity. Figure 28(a) and (b) show comparisons of cooling required for all three surfaces used on ITCB No. 2 over urethane and perlite, respectively. In both cases, the portion with the aluminum gray required the most cooling while the white portion required the least.

Radiative Cooling. Columns 8 and 9 of Table 4(c) show that, except for lines 15, 17, and 18, the membrane over the perlite radiates more than that over the urethane. Ratios in column 10 average 0.92, showing mild variations. Figure 29(a) and (b) present graphical representations of radiative cooling over urethane and perlite, respectively. Figure 29(c) shows that radiative cooling in the perlite portion is higher at the higher heat intensities. Radiative cooling relationships for all three surfaces on ITCB No. 2 are presented in Figure 30. Throughout all heat intensities, radiative cooling is significantly higher in the portion with a white surface.

Insulation Efficiency. As expected, columns 11 and 12 of Table 4(c) show that the urethane portion is considerably more efficient than the perlite. Ratios in column 13 are fairly uniform and average 1.52. Least squares lines of insulation efficiency for urethane and perlite portions are shown in Figure 31.

ITCB No. 3: 1 Inch Urethane/1-7/8 Inches Glass Fiber - Black Roof Surface

As indicated in Table 1, this roof provided R-values of 7.1 and 7.7 for urethane and glass fiber portions, respectively. Top surfacing was (1) black asphalt or (2) gray gravel. ITCB No. 3 was located at CEL, Port Hueneme, Calif., a seashore site where moderate summer and winter temperatures prevail. Relative energy factors for the black surface are shown in Table 5(a) and black surface temperatures for June 9-10, 1979 are presented in Figure 32.

Solar Heat Response. Columns 2 and 3 of Table 5(a) show only minor differences in solar heat response between the portions over urethane and glass fiber. Ratios of glass fiber to urethane in column 4 average 1.01. Highest membrane temperatures in columns 14 and 15 also show minor differences, with the higher of the two also alternating from one to the other.

Cooling Required. Columns 5 and 6 of Table 5(a) show very little difference between the two for cooling required. At the higher heat intensities, lines 1 through 6, the values over urethane are higher (except for line 5). At lower heat intensities, values over glass fiber are higher. Ratios average 1.01.

Radiative Cooling. Columns 8 and 9 of Table 5(a) show consistently higher radiation in the glass fiber portion. Ratios in column 10 average 1.24, which means that radiative cooling in the membrane over glass fiber was 1.24 times as high as that over the urethane.

Insulation Efficiency. Columns 11 and 12 of Table 5(a) show relatively minor differences between the two over all the heat intensities. The highest differences seem to be in the moderate heat intensity range, lines 5 through 7, where the efficiency of the glass fiber is higher. Ratios in column 13 average 1.01.

ITCB No. 3: 1 Inch Urethane/1-7/8 Inches Glass Fiber - Gray Gravel Roof Surface

Gray gravel surface temperatures for June 9-10, 1979 are shown in Figure 33. Except for the membrane temperatures during the hottest part of the day, there are very little differences between the urethane and glass fiber temperatures. Relative energy factors are presented in Table 5(b).

Solar Heat Response. Columns 2 and 3 of Table 5(b) show consistently higher values for the membrane over glass fiber. Column 4 indicates an average ratio of 1.09. Except for line 9, highest membrane temperatures in columns 14 and 15 are over the glass fiber. Ratios in column 16 average 1.02.

Cooling Required. Columns 5 and 6 of Table 5(b) show moderate variations, with the higher of the two switching from one to the other. The ratio of glass fiber to urethane in column 7 averages 0.96.

Radiative Cooling. Columns 8 and 9 of Table 5(b) indicate that in six of the 10 lines, the membrane over the urethane radiates more than that over the glass fiber; in line 10 they are equal and in the other three lines the membrane over the glass fiber radiates more. Ratios in column 10 average 0.97.

Insulation Efficiency. Columns 11 and 12 of Table 5(b) reveal that the efficiency of the glass fiber is consistently higher than the urethane. Ratios in column 13 are fairly uniform and average 1.13, which means that the glass fiber portion is an average of 13% more efficient than the urethane portion.

TEST RESULTS - WINTER

ITCB No. 2: 2-1/2 Inches Urethane/1 Inch Perlite - White Roof Surface

White surface temperatures for December 7-8, 1978 are shown in Figure 34. Target interior temperature for measurement of heating required is 68°F, whereas the target interior temperature for cooling (summer) was 75°F. Relative energy factors are presented in Table 6(a) which lists the coldest days at the top, based on outside temperature area from 0000 to 2400 (column 22).

Solar Heat Response. Columns 2 and 3 of Table 6(a) show low values of solar heat response as might be expected in winter with a white surface. Values over the perlite portion were consistently higher than over the urethane, whereas in summer, the opposite was true (see columns 2, 3, and 4 of Table 4(a)). Based on summer results, it was expected that the urethane portion with a white surface would contain slightly more heat than the perlite portion on a winter day, but that slight advantage is more than overcome by the higher temperature in the membrane over the perlite shown from 0000 to 0800 in Figure 34. Higher radiative cooling in the membrane over the urethane (columns 8 and 9 of Table 6(a)), as well as higher heat conduction through the perlite, makes the perlite portion warmer than the urethane portion.

Heating Required. The areas between the "below urethane" and "below perlite" temperature plots and the horizontal line for 68°F represent heating required for the urethane and perlite portions, respectively. Columns 5 and 6 of Table 6(a) show that consistently more heat is required in the perlite portion, as expected. Ratios of urethane to perlite in column 7 average 0.47 and indicate a trend toward lower ratios in the warmer winter days (lines 5 and 6).

Radiative Cooling. Columns 8 and 9 of Table 6(a) show consistently higher radiation in the membrane over the urethane. Ratios in column 10 average 2.08 but indicate a trend toward higher values as days are warmer (lines 5 and 6).

Insulation Efficiency. Columns 11 and 12 of Table 6(a) show that the urethane portion is consistently more efficient. Ratios in column 13 are fairly uniform and average 1.61. This ratio compares favorably with the corresponding ratio for insulation efficiency shown in column 13 of Table 4(a).

ITCB No. 2: 2-1/2 Inches Urethane/1 Inch Perlite - Aluminum Gray Roof Surface

Aluminum gray surface temperatures for December 7-8, 1978 are shown in Figure 35. Relative energy factors are presented in Table 6(b).

Solar Heat Response. Columns 2 and 3 of Table 6(b) show that neither of the two is consistently higher than the other, although solar heat response in the membrane over urethane is higher in four of the six cases. Ratios of urethane to perlite in column 4 are fairly low, indicating very little difference between the two.

Heating Required. Columns 5 and 6 of Table 6(b) show consistently higher values in the perlite portion. Ratios of urethane to perlite indicated in column 7 average 0.57, with a trend toward higher values in warmer days (lines 5 and 6).

Radiative Cooling. Columns 8 and 9 of Table 6(b) show that radiation is consistently higher in the membrane over urethane. Ratios in column 10 indicate considerable variations, with extreme values on warmer days (lines 5 and 6).

Insulation Efficiency. Columns 11 and 12 of Table 6(b) show consistently higher efficiency of the urethane portion, as expected. Ratios in column 13 are fairly uniform, averaging 1.57. This compares quite favorably with the average ratio in column 13 of Table 4(b) for summer.

ITCB No. 2: 2-1/2 Inches Urethane/1 Inch Perlite - Gray Gravel Roof Surface

Gray gravel surface temperatures for December 7-8, 1978 are quite similar to those shown in Figure 35 for the aluminum gray surface. Relative energy factors are shown in Table 6(c).

Solar Heat Response. Columns 2 and 3 of Table 6(c) show consistently higher heat response in the perlite portion. Ratios of urethane to perlite indicated in column 4 average 0.90. Figure 36(a) and (b) present solar heat response least squares lines for all three surfaces of ITCB No. 2 over urethane and perlite, respectively. Of the three surfaces, aluminum gray experiences the most heat and white the least. This same relationship among aluminum gray, gray gravel, and white was observed in Figure 26 for summer conditions.

Heating Required. Columns 5 and 6 of Table 6(c) show that the perlite portion requires consistently more heating than the urethane portion. Ratios of urethane to perlite in column 7 average 0.58. Figure 37(a) and (b) present least squares lines of heating required for all surfaces over urethane and perlite, respectively. The gray gravel surface required the most heating over urethane (Figure 37(a)), while the white surface required the most over perlite (Figure 37(b)).

Radiative Cooling. Columns 8 and 9 of Table 6(c) show that the urethane portion radiates consistently more heat than the perlite portion. The warmer days show extreme variations (lines 5 and 6). Ratios in column 10 average 9.94, but the ratios for lines 5 and 6 are so large that the overall average has little significance. The average ratio of the first four lines is 2.17. Figure 38(a) and (b) show least squares lines of radiative cooling for all surfaces over urethane and perlite, respectively. Both over urethane and over perlite, the white surface radiates the most and the aluminum gray the least.

Insulation Efficiency. Columns 11 and 12 of Table 6(c) show that the urethane portion is consistently more efficient than the perlite portion. Ratios in column 13 are fairly uniform and average 1.64. Figure 39(a) and (b) show least squares lines of insulation efficiency over urethane and perlite, respectively. Over both urethane and perlite, the white surface is most efficient. Over urethane the aluminum gray and gray gravel surfaces indicate about the same efficiency (Figure 39(a)), while the aluminum gray is slightly more efficient over perlite than the gray gravel (Figure 39(b)).

GENERAL DISCUSSION OF TEST RESULTS

Solar Heat Response

Each of the 26 lines in Table 3(a) represents one day, so the average shown at the bottom of the table is a daily average over a wide range of summer heat intensities. Plotting of daily values yields least squares lines as in Figure 5. Figure 40 is a compilation of the pertinent portions of Figures 11 and 26. Figure 40(a) shows the relationships over urethane, while Figure 40(b) presents relationships over perlite. The gap between white gravel and white surfaces is probably due to the "heat sink" capacity of the "gravel" portion of the white gravel.

Table 7 was constructed by obtaining the intercepts of the least squares lines in Figure 40 with selected outside temperature area values (measure of heat intensity). For a built-up roof with a black surface, the average solar heat response shown in column 4 of Table 7 (1.27) compares favorably with the average in column 4 of Table 3(a) (1.29). The overall average of 1.27 in Table 7 means that over a wide range of heat intensities, the black-surfaced membrane over urethane (R = 19.2) contained an average of 27% more solar heat response than the membrane over perlite (R = 2.8). One of the purposes of this study was to determine whether the increased thermal insulation required to meet demands for energy conservation would affect life and performance of built-up roof membranes placed over it. The authors believe that an increase of 27% in solar heat response in a built-up roof with a black surface will reduce significantly the effective life by accelerating decomposition of the bitumen, thereby contributing to early embrittlement and premature loss of flexibility of the membrane. The extra heat will also accelerate formation of blisters. Measurement of progressive embrittlement of asphalt was not possible in the relatively short timeframe of the study.

Average ratios for other surfacings in Table 7 indicate (1) 1.21 for aluminum gray, (2) 1.13 for gray gravel, (3) 1.01 for white gravel, and (4) 1.31 for white. Except for white gravel (1.01), these ratios are considered significant. In most cases, the ratios for hottest weather (top lines) are higher. One way to minimize solar heat response when the thermal resistance to heat flow must be increased is to place a portion of the insulation in the ceiling rather than putting all of it on the roof.

The rather dramatic influence of surface color on solar heat response is evident in both Figure 40(a) and (b). Table 8(a) and (b) show reductions in solar heat response due to roof surfacing over urethane and perlite, respectively. Columns 2 through 6 in Table 8(a) and (b) came from Table 7. For example, values in column 2 of Table 8(a) are identical to those in column 2 of Table 7. Likewise, values in column 2 of Table 8(b) are identical to those in column 3 of Table 7. Table 8(a) shows that at the highest heat intensity (top line of the table) solar heat response in a 4-ply built-up roof over 2-1/2 inches of urethane insulation can be reduced (1) 33.0% (column 7) by changing from black to aluminum gray, (2) 34.1% (column 8) by changing from black to gray gravel, (3) 64.8% (column 9) by changing from black to white gravel, and (4) 89.4% (column 10) by changing from black to white. Likewise, columns 11 through 13 list reductions by changing from aluminum gray to gray gravel, white gravel, and white, respectively. Columns 14 and 15 show reductions by changing from gray gravel to white gravel and white, respectively. Column 16 shows reductions by changing from white gravel to white. Obviously, a few of those changes in surfacings shown in Table 8 would be impractical, but most of them present reasonable alternatives to drastic roofing alterations to reduce energy consumption. Average reductions for the surface changes are shown in the last line of Table 8(a).

Table 8(b) reveals the same data for a 4-ply built-up roof over 1 inch of perlite insulation. These results are even more significant than those over urethane because many older roofs have 1 inch of perlite or equivalent thermal resistance. Depending on present surfacing, average reductions in solar heat response up to 89.2% (last line of column 10) can be achieved simply by changing surfacing, in this case from black to white. Such a reduction in solar heat response will reduce significantly the air conditioner loads during times of high summer heat.

To translate such reductions in solar heat response over perlite into more meaningful terms, Table 9 and Figure 41 were prepared. Values for columns 2 through 7 of Table 9 came from Table 8 and Figures 6, 21, 27, and 40. Figure 41 is a plot of data in columns 2 through 7 of Table 9. Using the average reductions in solar heat response presented in Table 8(b), Table 10 was constructed to show reductions in cooling required which correspond to certain reductions in solar heat response. Referring to Table 10(a), the solar heat response value of 700 in line 1 of column 3 is the highest solar heat response obtainable with the "black over perlite" curve in Figure 41. From Figure 41, the corresponding cooling required (495) is entered on line 1 of column 4.

When the surface is changed from black to aluminum gray, column 7 of Table 8(b) indicates an average reduction of 34.1% in solar heat response; this figure is entered in line 3 of column 3 in Table 10. The reduced solar heat response for line 2 of column 3 can then be calculated: 700 x (1.00 - 0.341) = 461. Using the "black over perlite" curve in Figure 41, the cooling required corresponding to a solar heat response of 461 is 226; this value is entered on line 2 of column 4 in Table 10. The reduction in cooling required which corresponds to a 34.1% reduction in solar heat response is then calculated as follows: 495 - 226 ÷ 495 x 100 = 54.3%. Thus a change in surface from black to aluminum gray reduces the solar heat response by 34.1% but also reduces cooling required by 54.3%. Similarly, column 10 of Table 10 shows that a change from black to white reduces cooling required by 93.1%.

Table 10(b) and (c) show reductions in cooling required when roof surface is changed from aluminum gray and from gray gravel, respectively. Admittedly, some of the changes are impractical, but all are presented for completeness.

When aluminum gray is changed to white, Table 8(b) shows a reduction of 83.4% (column 13) in solar heat response and Table 10(b) indicates a corresponding reduction of 94.1% (column 8) in cooling required. In winter, the effects of changing from aluminum gray to white are somewhat different. Table 6 shows relative energy factors for winter. In this discussion, the most important energy factor is heating required, because it is involved throughout the entire day, 0000 to 2400, as shown in Figures 34 and 35. Figure 37 presents appropriate data for winter. Table 11 was constructed by taking intercepts of the lines on Figure 37(b) with selected outside temperature area values. Data corresponding to the coldest weather appear on the top line of Table 11.

Columns 2 and 4 of Table 11 show heating required. Ratios of white to aluminum gray are listed in column 6. In the coldest weather (top line) the ratio is 1.16 which means that a change from aluminum gray to white would result in heating requirement 16% higher. The overall average increase of 19% shown at the bottom of column 6 does not approach the order of magnitude of the reduction in cooling required in summer (94.1%). Since we are dealing with time-temperature "areas" and not "heat units," these comparisons must be viewed as relative.

Radiative Cooling

Figure 42(a) and (b) show radiative cooling relationships for all surfaces of ITCB No. 1 and No. 2 over urethane and over perlite, respectively. Except for the coolest temperatures (left side of graph), the white surface shows highest radiative cooling in both cases. Columns 2 through 6 of Table 12(a) and (b) give the ordinates on the respective curves corresponding to the outside temperature values shown in column 1 over urethane and perlite, respectively. Columns 7 through 10 show ratios between radiative cooling for the gray gravel surface and the other surfaces. Average ratios in Table 12 show little differences between gray gravel and aluminum gray (column 7) but increasing differences for the other surfaces, with the white surface having the highest ratio both over urethane (1.92) and over perlite (1.67).

For a given surface, differences in radiative cooling over urethane and over perlite are pr .ented in Table 13. Radiative cooling data for Table 13 came from Table 12. For example, column 2 of Table 13 came from column 5 of Table 12(a) and column 3 of Table 13 came from column 5 of Table 12(b). For each of the surfaces, the third column (4, 7, 10, 13, and 16) shows ratios between urethane and perlite. Overall average ratios show that with black (column 4), white gravel (column 7), and white (column 10), radiative cooling is higher over the urethane (R = 19.2) than the perlite (R = 2.8) by 28%, 27%, and 6%, respectively. Radiative cooling over perlite is slightly higher than over the urethane in membranes with surfaces of aluminum gray (column 13) and gray gravel (column 16).

Table 6 shows that in winter the radiative cooling for all surfaces is consistently higher in the membrane over urethane. As in the summer, the highest radiative cooling took place in the membrane with a white surface.

Since all measurements and analyses in this study were conducted under non-steady state conditions, it is not expected that heat flow equations based on steady state assumptions will apply. The authors acknowledge the basic value of mathematical equations for expressing engineering phenomena. We believe that experiments in the "real world" also contribute to the general store of knowledge and sometimes open doors to new approaches to understanding these phenomena.

It has been suggested that the heat capacity (specific heat) of insulation has a profound influence on the surface temperatures it experiences. That is, a built-up roof containing an insulation with a high heat capacity would be expected to show higher surface temperatures than one containing an insulation with a low heat capacity. Thus, if urethane has a significantly higher heat capacity than perlite, the built-up roof over urethane should show higher temperatures. An investigation of measured or observed specific heat values shows that there is considerable confusion as to what the values are for any of the customary insulations used in roofing. Some authorities show a higher specific heat for urethane than for perlite and other sources show that they are about the same. Still, others do not show any specific heats at all. The authors believe that until the true specific heats can be determined, this matter must remain unresolved. From the data presented in this report, a built-up roof over 2-1/2 inches of urethane will be considerably hotter than one over 1 inch of perlite.

CONCLUSIONS

1. Other things being equal, a built-up roof membrane placed over insulation with high thermal resistance will be subjected to significantly higher temperatures than one placed over insulation with a low thermal resistance. These higher temperatures are likely to reduce the service life of a black roof by accelerating decomposition and embrittlement of bitumens. Higher temperatures will occur whether the high thermal resistance is obtained with one thickness of board stock or with multiple layers and regardless of the roof surfacing, although some light colored surfacings greatly reduce the order of magnitude and overall effect of the higher temperatures.

2. Color and type of roof surfacing directly affect the solar heat response and radiative cooling of a built-up roof. To minimize membrane temperature effects on built-up roofs, surfacings in order of best to worst are (1) white, (2) white gravel, (3) gray gravel, (4) aluminum gray, and (5) black.

3. Over a wide range of heat intensities, the black-surfaced membrane over urethane (R = 19.2) showed an average of 27% higher solar heat response than the membrane over perlite (R = 2.8).

4. At the highest heat intensities in summer, solar heat response in a 4-ply built-up roof over 2-½ inches of urethane can be reduced (1) 33.0% by changing the top surfacing from black to aluminum gray, (2) 34.1% by changing from black to gray gravel, (3) 64.8% by changing from black to white gravel, and (4) 89.4% by changing from black to white. Over the whole range of heat intensities, the average reduction in solar heat response by changing from black to white is 88.8%.

5. At the highest heat intensities in summer, solar heat response in a 4-ply built-up roof over 1 inch of perlite can be reduced (1) 29.5% by changing top surfacing from black to aluminum gray, (2) 30.9% by changing from black to gray gravel, (3) 56.1% by changing from black to white gravel, and (4) 89.9% by changing from black to white. Over the whole range of heat intensities, the average reduction in solar heat response by changing from black to white is 89.2%.

6. Reductions in solar heat response also result in corresponding reductions in cooling required. Over 1 inch of perlite, an average reduction of 89.2% in solar heat response when black is changed to white also results in a 93.1% reduction in cooling required.

7. Advantages gained by changing surfacing to reduce solar heat response and cooling required in summer far outweigh the corresponding slight increases in heat required in winter.

8. There may be an optimum economic thickness of insulation for a given type of built-up roof.

RECOMMENDATIONS

1. When it is necessary to improve thermal resistance of an existing roof to reduce energy consumption, serious consideration should be given to changing the surfacing to a lighter color as an alternative to more expensive reroofing. Another alternative is to place additional insulation in the ceiling to avoid increasing the membrane temperatures by adding insulation to the roof.

2. When possible in new roof design, it is recommended that provisions be made to place the bulk of the insulation in the ceiling rather than on the roof.

3. When there is no ventilated area with a ceiling and all insulation required for energy conservation must be placed on the roof, it is strongly recommended that it have the lightest colored surfacing commensurate with the design. For example, if the roof is to be smooth surfaced, a white coating should be specified; if the roof is to be gravelled, white gravel (limestone) is preferred.

4. To determine the optimum economic thickness of insulation, studies of the type reported herein should be made on built-up roofs containing at least three different thicknesses of the same insulation type.

5. Comparable studies should be made of spray-applied polyurethane foam roofs to determine temperature-time effects of various foam-coating combinations.

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REFERENCES

1. "NRCA tells how to stop roof problems caused by new insulation guidelines," American Roofer and Building Improvement Contractor, Nov-Dec 1974, p 5.

2. National Bureau of Standards. Technical Note 231: Solar heating, radiative cooling, and thermal movement - their effects on built-up roofing, by W. C. Cullen. Dec 1963.

3. W. C. Cullen and W. H. Appleton. "Effect of insulation on the weathering of smooth-surfaced, built-up roofs exposed to solar heating," Construction Specifier, 16(5), Oct 1963, pp 35-38.

4. National Bureau of Standards. NBSIR 76-987: Effect of insulation on the surface temperature of roof membranes, by W. J. Rossiter, Jr. and R. G. Mathey. Feb 1976.

5. Civil Engineering Laboratory. Contract Report CR 80.001: Building insulation materials compilation, by J. G. Bourne et al. Cambridge, Mass., Dynatech R/D Co., Division of Dynatech Corp., Jan 1980.

Table 1. Experimental Built-Up Roofs on Insulated Temperature-Controlled Buildings (ITCB)

ITCB Number	Insulations Used	Thermal Resistance	Top Surfacing	Location
1	2-½-in. urethane/1-in. perlite	19.2/2.8	black/white gravel	NWC China Lake, CA[a]
2	2-½-in. urethane/1-in. perlite	19.2/2.8	white/aluminum gray/gray gravel	NWC China Lake, CA
3	1-in. urethane/1-7/8-in. glass fiber	7.1/7.7	black/gray gravel	CEL Port Hueneme, CA[b]

[a] A high desert site.

[b] A seashore site.

Table 2. Hourly Temperature ($^{\circ}F$) Data for June 7-8, 1978; ITCB No. 1

Time of Day	Top of BUR				Top of Insulation				Below Insulation				Inside ITCB	Outside Air
	Black		White Gravel		Black		White Gravel		Black		White Gravel			
	U[a]	P[b]	U	P	U	P	U	P	U	P	U	P		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
7 June 1978														
0000	66	68	6[illegible]	[illegible]	66	68	70	70	73	72	73	73	74	80
0100	64	66	[illegible]	65	64	67	67	68	73	71	73	72	74	77
0200	62	65	64	67	62	65	65	66	73	71	73	71	73	76
0300	60	61	61	63	60	62	62	63	72	70	73	71	74	73
0400	57	59	59	62	57	60	59	61	72	70	73	70	74	71
0500	56	61	57	62	56	59	58	60	72	69	72	69	74	73
0600	58	62	58	64	57	61	58	61	72	69	72	70	72	71
0700	64	67	61	68	63	66	61	64	72	70	72	70	73	79
0800	96	92	70	76	93	92	65	67	72	73	72	71	72	84
0900	130	130	92	108	130	128	91	96	74	85	73	76	74	91
1000	158	151	112	126	155	148	112	116	77	92	74	84	72	99
1100	177	165	131	134	175	165	125	126	80	99	77	88	72	104
1200	187	174	144	144	186	174	140	140	83	104	79	93	73	104
1300	190	170	159	142	190	176	156	154	85	105	81	96	73	106
1400	186	160	152	144	184	169	152	151	86	105	82	96	75	115
1500	167	146	138	130	168	153	139	133	87	103	83	96	77	111
1600	150	135	122	123	151	140	128	124	86	97	83	92	75	108
1700	135	126	118	116	134	128	120	116	84	93	82	90	73	108
1800	116	112	107	102	116	111	109	106	82	88	81	86	74	104
1900	100	99	98	98	101	98	100	97	80	83	79	83	74	100
2000	85	83	87	86	85	83	89	86	78	78	78	79	74	93
2100	71	71	76	76	71	72	78	77	76	74	76	76	72	86
2200	69	72	72	75	69	71	73	73	74	72	75	73	72	84
2300	70	74	72	76	69	72	72	73	73	72	74	73	74	84
8 June 1978														
0000	72	73	72	75	70	72	72	73	73	72	74	73	72	82
0100	69	71	71	73	68	70	71	71	73	72	73	73	74	81
0200	67	70	69	71	67	70	69	70	73	72	73	72	73	79
0300	64	68	67	70	65	68	68	69	73	72	73	72	74	78
0400	62	63	64	67	61	64	65	66	73	71	73	71	73	75
0500	57	58	60	62	57	59	61	61	72	70	73	70	71	73
0600	[illegible]	59	58	61	56	59	58	59	72	69	72	69	74	71
0700	60	62	58	63	59	62	58	60	72	70	72	70	74	72
0800	93	95	65	74	89	89	61	63	72	72	72	70	74	81
0900	128	128	93	104	128	126	87	93	74	84	72	75	71	88
1000	158	149	116	124	154	145	110	114	77	91	74	83	72	98
1100	177	164	130	135	174	163	124	125	80	99	76	88	74	104
1200	184	170	141	140	183	171	138	138	83	103	79	93	72	103
1300	192	178	150	150	190	178	146	145	85	106	81	96	75	113
1400	186	170	148	144	187	174	148	146	86	106	82	98	74	110
1500	178	162	146	138	180	169	146	144	87	105	83	97	74	108
1600	160	144	134	129	160	148	134	129	86	100	83	94	76	110
1700	136	122	120	116	138	127	122	118	85	94	83	91	77	107
1800	119	113	110	110	119	113	111	108	83	89	81	87	76	107
1900	102	101	100	101	102	99	101	99	80	84	80	84	73	102
2000	87	87	90	89	87	86	92	89	78	80	78	81	72	94
2100	78	80	82	83	78	78	83	81	76	76	77	77	74	91
2200	78	81	80	83	77	79	80	80	75	74	75	76	74	89
2300	76	78	78	80	75	77	79	78	74	74	75	75	72	86

[a] U = Urethane

[b] P = Perlite

Table 3. Relative Energy Factors Defined by Measured Areas; ITCB No. 1, Summer

Line No.	Solar Heat Response: U	Solar Heat Response: P	Solar Heat Response: Ratio	Cooling Required: U	Cooling Required: P	Cooling Required: Ratio	Radiative Cooling: U	Radiative Cooling: P	Radiative Cooling: Ratio	Insulation Efficiency: U	Insulation Efficiency: P	Insulation Efficiency: Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Black Surface												
1	595	456	1.30	237	[illegible]	[illegible]	[illegible]	[illegible]	1.29	[illegible]	[illegible]	[illegible]
2	618	486	1.27	246	[illegible]	0.62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	550	388	1.42	224	371	0.60	[illegible]	[illegible]	1.16	[illegible]	638	[illegible]
4	628	491	1.28	199	354	0.56	[illegible]	[illegible]	1.22	[illegible]	[illegible]	[illegible]
5	703	563	1.25	108	292	0.37	211	[illegible]	1.28	[illegible]	[illegible]	1.30
6	733	602	1.22	113	301	0.38	[illegible]	153	1.22	1062	[illegible]	[illegible]
7	690	524	1.32	157	297	0.53	149	[illegible]	1.34	[illegible]	[illegible]	[illegible]
8	658	513	1.28	42	264	0.35	[illegible]	236	1.25	[illegible]	[illegible]	[illegible]
9	703	549	1.28	138	284	0.49	175	139	1.24	[illegible]	[illegible]	1.52
10	582	440	1.32	80	235	0.34	206	171	1.20	[illegible]	[illegible]	1.55
11	503	382	1.32	75	214	0.35	175	151	1.16	786	527	1.49
12	675	522	1.29	87	245	0.36	204	151	1.35	938	623	1.51
13	520	373	1.39	71	201	0.35	147	120	1.22	776	505	[illegible]
14	707	594	1.19	89	252	0.35	157	130	1.21	[illegible]	620	1.49
15	749	599	1.25	84	256	0.33	189	158	1.28	968	[illegible]	1.50
16	580	454	1.28	74	209	0.35	151	120	1.26	[illegible]	505	1.53
17	755	618	1.22	82	243	0.34	139	127	1.09	[illegible]	625	1.49
18	497	393	1.26	56	179	0.31	185	148	1.25	678	436	[illegible]
19	399	288	1.38	33	124	0.27	128	94	1.36	515	315	1.63
20	628	522	1.20	50	181	0.28	189	135	1.40	[illegible]	[illegible]	1.51
21	281	205	1.37	26	92	0.28	129	98	1.31	389	251	1.55
22	342	255	1.34	28	104	0.27	124	92	1.35	438	275	1.59
23	425	307	1.38	28	116	0.24	164	119	1.38	510	309	1.65
24	451	330	1.37	25	98	0.26	183	136	1.35	511	313	1.63
25	273	221	1.24	12	61	0.20	172	125	1.38	316	209	1.51
26	360	254	1.42	17	71	0.24	102	67	1.52	366	199	1.84
avg	---	---	1.29	--	--	0.37	---	--	1.28	---	---	1.53
White Gravel Surface												
1	187	194	0.96	205	295	0.69	164	126	1.30	681	582	1.19
2	197	200	0.98	219	306	0.72	129	92	1.40	640	540	1.19
3	279	262	1.06	71	200	0.36	195	162	1.20	638	493	1.29
4	293	285	1.03	70	216	0.32	174	146	1.19	670	527	1.27

Line No.	EPP Membrane Temperature (°F), Highest: U	Highest: P	Highest: Ratio	Lowest: U	Lowest: P	Outside Air Temperature: Highest	Lowest	Area	Area	[illegible]
(1)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	[illegible]
Black Surface										
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.87	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	139	[illegible]	[illegible]	58	100	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	58	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2070	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
avg	---	---	[illegible]	--	--	--	--	--	--	-
White Gravel Surface										
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	148	143	[illegible]	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	148	148	[illegible]	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 3. Continued

Line No.	Solar Heat Response[a]			Cooling Required[b]			Radiative Cooling			Insulation Efficiency[d]			BUR Membrane Temperature (°F)					Outside Air Temperature (°F)				Date
													Highest			Lowest						
	U[e]	P[e]	Ratio[f]	U	P	Ratio	U	P	Ratio	U	P	Ratio	U	P	Ratio	U	P	Highest	Lowest	Area[g]	Area[h]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
5	229	227	1.01	128	192	0.67	166	122	1.36	[illegible]	[illegible]	1.18	[illegible]	[illegible]	[illegible]	[illegible]	60	108	69	1384	2689	8-9-77
6	233	243	0.96	114	183	0.62	149	112	1.33	543	465	1.17	141	[illegible]	[illegible]	[illegible]	[illegible]	116	64	1373	[illegible]	8-8-77
7	288	290	0.99	53	172	0.31	155	128	1.21	577	[illegible]	1.29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	111	58	1328	[illegible]	6-17-78
8	166	148	1.12	32	166	0.19	94	81	1.16	429	326	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	102	74	1310	2599	6-18-78
9	192	185	1.04	42	122	0.34	137	104	1.32	420	328	1.28	128	124	[illegible]	[illegible]	61	100	68	1287	2532	9-11-77
10	150	152	0.99	31	96	0.32	163	126	1.29	[illegible]	293	[illegible]	121	117	[illegible]	[illegible]	60	[illegible]	67	1259	[illegible]	9-12-77
11	220	217	1.01	23	90	0.26	176	121	[illegible]	360	293	[illegible]	123	[illegible]	[illegible]	[illegible]	49	94	55	1172	[illegible]	[illegible]
12	[illegible]	123	1.14	16	55	0.18	135	104	1.30	248	187	[illegible]	104	[illegible]	[illegible]	[illegible]	56	91	64	1149	2246	[illegible]
13	149	152	0.98	11	50	0.22	156	110	[illegible]	237	[illegible]	[illegible]	[illegible]	111	1.02	[illegible]	[illegible]	89	52	1080	[illegible]	[illegible]
14	93	98	0.95	1	26	0.03	152	110	1.38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	87	56	[illegible]	[illegible]	10-19-77
avg	--	--	1.02	--	--	0.37	---	---	[illegible]	---	---	[illegible]	---	---	[illegible]	--	--	--	--	--	--	--

[a]Solar Heat Response is the area of that portion of the membrane temperature plot which is above the outside air temperature plot.

[b]Cooling Required is the area of that portion of the below insulation plot which is above the [illegible]°F line.

[c]Radiative Cooling is the area of that portion of the membrane temperature plot which is below the outside temperature plot.

[d]Insulation Efficiency is the area of that portion of the membrane temperature plot which is above the below insulation plot.

[e]U = Urethane; P = Perlite.

[f]Ratios shown in this table are urethane to perlite, i.e., higher R to lower R.

[g]The area of the outside temperature plot from 0800 to 1900, referred to a base line of 0°F.

[h]The area of the outside temperature plot from 0000 to 2400, referred to a base line of 0°F.

Table [illegible]. Relative Energy Factors Defined by Measured Areas; ITCB No. 2, Summer

Site No.	[illegible]	P	Rat.	[illegible]	[illegible]	Rat.	[illegible]	[illegible]	Rat.	[illegible]	[illegible]	Rat.	Surface Temperature (°F) Highest	[illegible]	Rat.	Lowest	[illegible]	Outside Air Temperature (°F) Highest	Lowest	Area[a]	Area[b]	Date
																		(19)	(20)	(21)	(22)	(23)
[illegible]																						
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	82	1514	2980	8-7-78
2	[illegible]	36	1.58	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80	1505	2935	8-5-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8-6-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8-5-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68	[illegible]	2762	7-21-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	73	1439	[illegible]	7-22-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68	1416	[illegible]	8-29-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2656	8-28-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9-2-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9-1-78
11	22	61	1.18	11	86	0.13	171	156	1.10	257	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2332	8-23-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2310	8-23-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9-9-78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9-10-78
[illegible]	--	--	[illegible]	--	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--
[illegible]																						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2980	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	482	449	[illegible]	[illegible]	472	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2925	[illegible]
[illegible]	459	377	1.22	122	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	413	332	1.24	126	344	0.37	[illegible]	[illegible]	0.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.04	[illegible]	66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	549	450	1.22	116	368	[illegible]	[illegible]	[illegible]	0.98	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.22	105	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	330	[illegible]	98	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	363	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(continued)

Table 4. Continued

Line No.	Solar Heat Response[a] U[e]	P[e]	Ratio[f]	Cooling Required[b] U	P	Ratio	Radiative Cooling[c] U	P	Ratio	Insulation Efficiency[d] U	P	Ratio	Membrane Temperature (°F) Highest U	P	Ratio	Lowest U	P	Outside Air Temperature (°F) Highest	Lowest	Area[g]	Area[h]	Date
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
13	363	288	1.26	80	235	[illegible]	139	134	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	370	301	1.23	73	[illegible]	0.32	131	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	359	307	1.17	49	179	0.27	[illegible]	80	1.18	513	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1229	[illegible]	[illegible]
16	377	331	1.14	48	168	0.29	83	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	248	195	1.27	23	104	0.22	122	100	1.22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	158	152	1.04	12	68	0.18	57	[illegible]	1.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
avg	---	---	1.22	--	--	0.31	--	--	1.00	---	---	[illegible]	---	---	[illegible]	--	--	--	--	--	--	--
										Gra[illegible] Gravel Surface												
1	450	368	1.22	79	318	0.25	127	156	0.81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	465	[illegible]	1.24	83	320	0.26	107	138	0.78	939	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	448	370	1.21	81	317	0.26	102	131	0.78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	418	337	1.24	70	298	0.23	133	158	0.84	888	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	404	343	1.18	78	306	0.25	138	150	0.92	881	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8-2-79
6	391	340	1.15	71	295	0.24	113	132	0.86	826	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	466	386	1.21	72	295	0.24	118	129	0.91	[illegible]	571	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	424	347	1.22	65	273	0.24	114	135	0.84	[illegible]	532	1.56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	416	371	1.12	66	280	0.24	106	125	0.85	822	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	345	292	1.18	51	236	0.22	155	168	0.92	700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	422	368	1.15	66	267	0.25	115	133	0.86	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	448	364	1.23	59	250	0.24	142	153	0.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	287	252	1.14	45	196	0.23	122	135	0.90	601	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	295	266	1.11	43	197	0.22	121	123	0.98	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	312	283	1.10	29	163	0.18	74	68	1.09	398	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	333	299	1.11	28	151	0.19	60	61	0.98	477	411	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	155	145	1.07	7	83	0.08	133	118	1.13	300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	100	119	0.84	1	50	0.02	43	39	1.10	166	126	1.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
avg	---	---	1.15	--	--	0.21	--	--	0.92	---	---	[illegible]	---	---	[illegible]	--	--	--	--	--	--	--

[a]Solar Heat Response is the area of that portion of the membrane temperature plot which is above the outside air temperature plot.

[b]Cooling Required is the area of that portion of the below insulation plot which is above the [illegible]°F line.

[c]Radiative Cooling is the area of that portion of the membrane temperature plot which is below the outside temperature plot.

[d]Insulation Efficiency is the area of that portion of the membrane temperature plot which is above the below insulation plot.

[e]U = Urethane; P = Perlite.

[f]Ratios shown in this table are urethane to perlite, i.e., higher R to lower R.

[g]The area of the outside temperature plot from 0800 to 1900, referred to a base line of 0°F.

[h]The area of the outside temperature plot from 0000 to 2400, referred to a base line of 0°F.

Table 5. Relative Energy Factors Defined by Measured Areas; ITCB No. 3, Summer

Line No.	Solar Heat Response[a]			Cooling Required[b]			Radiative Cooling[c]			Insulation Efficiency[d]			BUR Membrane Temperature (°F)					Outside Air Temperature (°F)				[illegible]
													Highest			Lowest						
	U[e]	GF[e]	Ratio[f]	U	GF	Ratio	U	GF	Ratio	U	GF	Ratio	U	GF	Ratio	U	GF	Highest	Lowest	Area[g]	Area[h]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
											Black Surface											
1	625	623	1.00	512	509	0.99	83	100	[illegible]	473	478	1.01	165	168	1.02	59	57	[illegible]	[illegible]	1219	[illegible]	6-10-79
2	613	590	0.96	440	436	0.99	65	84	1.29	448	427	0.95	155	153	0.99	56	55	101	60	1179	2205	5-13-79
3	665	650	0.98	391	384	0.98	84	93	1.11	466	468	1.00	160	158	0.99	52	52	86	57	1116	2142	6-9-79
4	619	611	0.99	325	319	0.98	56	71	1.27	433	419	0.97	151	146	0.97	52	[illegible]	96	56	1082	2070	5-12-79
5	483	525	1.09	90	97	1.08	70	88	1.26	400	435	1.09	129	136	1.05	53	53	79	59	1071	2063	8-26-79
6	579	590	1.02	129	121	0.94	68	86	1.26	481	506	1.05	146	145	0.99	53	52	83	61	1059	2114	8-27-79
7	460	490	1.06	80	89	1.11	82	95	[illegible]	375	403	1.08	127	131	1.03	51	50	79	59	1025	2034	8-22-79
8	615	614	1.00	238	241	1.01	60	81	1.35	420	406	0.97	146	144	0.99	46	45	86	52	1022	1958	5-11-79
9	527	519	0.98	95	96	1.01	57	60	1.05	398	396	0.99	141	135	0.96	55	56	77	58	1000	2009	8-21-79
10	667	654	0.98	202	205	1.01	51	73	1.43	447	436	0.98	131	139	0.99	45	44	80	49	981	1857	5-10-79
avg	---	---	1.01	---	---	1.01	--	--	[illegible]	---	---	1.01	---	---	1.00	--	--	--	--	--	--	--
											Gray Gravel Surface											
1	452	496	1.10	432	453	1.05	81	79	0.98	334	385	1.17	149	154	1.03	60	60	105	64	1219	2327	6-10-79
2	474	494	1.04	373	382	1.02	49	61	1.24	330	366	1.11	136	148	1.01	58	58	101	60	1179	2205	5-13-79
3	443	493	1.11	307	319	1.04	55	54	0.98	311	360	1.16	139	145	1.04	54	54	86	57	1116	2142	6-9-79
4	442	481	1.09	251	268	1.07	46	49	1.06	286	325	1.14	131	135	1.03	54	54	96	56	1082	2070	5-12-79
5	346	377	1.09	43	33	0.77	56	54	0.96	302	345	1.14	114	119	1.04	53	55	79	59	1071	2063	8-26-79
6	429	447	1.04	63	52	0.82	58	56	0.97	390	428	1.10	127	128	1.01	54	54	83	61	1059	2114	8-27-79
7	290	323	1.11	33	26	0.79	69	61	0.88	256	294	1.15	109	113	1.04	53	54	79	59	1025	2034	8-22-79
8	435	481	1.10	185	195	1.05	49	46	0.94	288	324	1.12	133	136	1.02	49	49	86	52	1022	1958	5-11-79
9	365	393	1.08	51	43	0.84	38	25	0.66	283	316	1.12	120	118	0.98	56	57	77	58	1000	2009	8-21-79
10	461	509	1.10	141	157	1.11	34	34	1.00	296	336	1.14	131	136	1.04	47	47	80	49	981	1857	5-10-79
avg	---	---	1.09	---	---	0.96	--	--	0.97	---	---	1.13	---	---	1.02	--	--	--	--	--	--	--

[a] Solar Heat Response is the area of that portion of the membrane temperature plot which is above the outside air temperature plot.

[b] Cooling Required is the area of that portion of the below insulation plot which is above the 75°F line.

[c] Radiative Cooling is the area of that portion of the membrane temperature plot which is below the outside temperature plot.

[d] Insulation Efficiency is the area of that portion of the membrane temperature plot which is above the below insulation plot.

[e] U = Urethane; GF = Glass Fiber

[f] Ratios shown in this table are urethane to perlite, i.e., higher R to lower R.

[g] The area of the outside temperature plot from 0800 to 1900, referred to a base line of 0°F.

[h] The area of the outside temperature plot from 0000 to 2400, referred to a base line of 0°F.

Table 6. Relative Energy Factors Defined by Measured Areas; HCB No. 2, Winter

Line No.	Solar Heat Response[a]			Heating Required			Radiative Cooling[c]			Insulation Efficiency[d]			[illegible] Membrane Temperature [illegible]					Outside Air Temperature (°F)				Date
	U[e]	P[e]	Ratio[f]	U	P	Ratio	U	P	Ratio	U	P	Ratio	U	P	Ratio	U	P	Highest	Lowest	Area[g]	Area[h]	
(1)	(2)	(3)	(4)	(5)	(6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
											White Surface											
1	16	30	0.53	[illegible]	632	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	26	0.38	312	390	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	221	522	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	542	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	33	[illegible]	176	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	23	37	[illegible]	101	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1397	[illegible]
6	35	48	[illegible]	80	234	[illegible]	66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
avg	--	--	0.59	---	---	0.47	---	---	2.08	--	---	1.61	--	--	0.95	--	--	--	--	---	--	---
											Aluminum Gray Surface											
1	216	200	1.08	348	529	0.66	159	49	3.24	567	556	1.56	81	79	1.02	6	15	31	16	[illegible]	852	12-8-78
2	135	140	0.96	314	509	0.62	139	47	2.96	821	533	1.54	64	64	1.00	11	17	[illegible]	[illegible]	528	940	12-7-78
3	156	153	1.02	274	444	0.62	108	43	2.51	731	484	1.51	76	76	1.00	19	24	[illegible]	[illegible]	[illegible]	1054	12-6-78
4	161	148	1.09	177	311	0.57	84	13	6.46	645	420	1.54	100	94	1.06	27	31	65	[illegible]	[illegible]	1284	12-5-78
5	172	177	0.97	103	217	0.47	55	1	55.00	511	315	1.62	87	95	1.02	33	38	[illegible]	[illegible]	709	1397	1-7-79
6	179	173	1.03	88	193	0.46	32	1	32.00	483	297	1.63	93	88	1.06	39	43	58	[illegible]	715	1434	1-8-79
avg	---	---	1.02	---	---	0.57	--	--	17.03	---	---	1.57	--	--	1.03	--	--	--	--	---	--	---
											Gray Gravel Surface											
1	161	189	0.85	388	596	0.65	180	93	1.94	877	537	1.63	75	76	0.99	7	12	31	[illegible]	[illegible]	852	12-8-78
2	119	138	0.86	345	565	0.61	172	85	2.02	838	519	1.61	62	64	0.97	11	15	[illegible]	[illegible]	[illegible]	940	12-7-78
3	130	146	0.89	304	495	0.61	144	63	2.28	750	463	1.62	73	74	0.99	17	22	48	25	554	1054	12-6-78
4	126	134	0.94	201	356	0.56	102	42	2.43	645	401	1.61	91	90	1.01	26	30	65	[illegible]	698	1284	12-5-78
5	151	156	0.97	127	245	0.52	54	3	18.00	495	294	1.68	80	78	1.02	33	37	[illegible]	[illegible]	[illegible]	1397	1-7-79
6	142	162	0.88	111	222	0.50	33	1	33.00	468	275	1.70	95	87	0.98	38	41	[illegible]	[illegible]	715	1434	1-8-79
avg	---	---	0.90	---	---	0.58	---	--	9.94	---	---	1.64	—	--	0.99	--	--	--	--	---	--	---

[a]Solar Heat Response is the area of that portion of the membrane temperature plot which is above the outside air temperature plot.

[b]Cooling Required is the area of that portion of the below insulation plot which is above the 75°F line.

[c]Radiative Cooling is the area of that portion of the membrane temperature plot which is below the outside temperature plot.

[d]Insulation Efficiency is the area of that portion of the membrane temperature plot which is above the below insulation plot.

[e]U = Urethane; P = Perlite.

[f]Ratios shown in this table are urethane to perlite, i.e., higher R to lower R.

[g]The area of the outside temperature plot from 0800 to 1900, referred to a base line of 0°F.

[h]The area of the outside temperature plot from 0000 to 2400, referred to a base line of 0°F.

Table 7. Solar Heat Response Ratios Between Urethane and Perlite Portions; Overall Values, Summer

Outside Temperature Area[a]	Black			Aluminum Gray			Gray Gravel			White Gravel			White		
	U[b]	P[c]	Ratio[d]	U	P	Ratio	U	P	Ratio	U	P	Ratio	U	P	Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1600	895	695	1.29	600	490	1.22	590	480	1.23	315	305	1.03	95	70	1.36
1500	780	610	1.29	515	425	1.21	495	410	1.21	275	270	1.02	85	60	1.42
1400	670	525	1.28	435	355	1.22	395	335	1.18	235	230	1.02	75	55	1.36
1300	555	440	1.26	350	290	1.21	300	265	1.13	195	195	1.00	60	45	1.33
1200	440	355	1.24	270	225	1.20	205	195	1.05	155	155	1.00	50	40	1.25
1100	330	265	1.24	185	155	1.19	105	125	--	115	115	1.00	40	35	1.14
avg	---	---	1.27	---	---	1.21	---	---	1.13	---	---	1.01	--	--	1.31

[a] From 0800 to 1900.

[b] U = 2-½ inches urethane.

[c] P = 1 inch perlite.

[d] Ratios shown are urethane to perlite, i.e., higher R to lower R.

Table 8. Reductions in Solar Heat Response Due to Roof Surface in Urethane/Perlite Built-Up Roofs; ITCB No. 1 and No. 2, Summer

Outside Temperature Area[a]	Black	Aluminum Gray	Gray Gravel	White Gravel	[illegible]	% Reduction From Black Surface to [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1)	(2)	(3)	(4)	(5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1600	895	600	570	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1500	780	515	495	[illegible]	85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1400	670	435	395	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1300	555	350	300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1200	440	270	205	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1100	330	185	105	115	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ave	---	---	---	---	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68.2
[illegible] Perlite															
1600	695	490	480	305	70	[illegible]	[illegible]	56.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	77.0
1500	610	425	410	270	[illegible]	30.3	[illegible]	[illegible]	[illegible]	3.5	[illegible]	[illegible]	[illegible]	[illegible]	77.8
1400	525	355	335	230	55	[illegible]	36.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.1
1300	440	290	265	195	[illegible]	[illegible]	39.8	[illegible]	80.8	8.6	42.8	[illegible]	[illegible]	[illegible]	76.9
1200	355	225	195	155	[illegible]	36.6	[illegible]	[illegible]	[illegible]	13.3	41.1	[illegible]	20.5	[illegible]	[illegible]
1100	265	155	125	115	35	41.5	[illegible]	56.6	86.8	[illegible]	25.8	[illegible]	[illegible]	[illegible]	69.6
ave	---	---	---	---	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[a]From 0800 to 1900.

Table 9. Solar Heating Response and Cooling Required Over Perlite; ITCB No. 1 and No. 2, Summer

Outside Temperature Area[a]	Black Over Perlite		Aluminum Gray Over Perlite		Gray Gravel Over Perlite	
	Solar Heat Response	Cooling Required	Solar Heat Response	Cooling Required	Solar Heat Response	Cooling Required
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1600	695	487	490	488	480	400
1500	610	383	425	391	410	318
1400	525	292	355	298	335	247
1300	440	211	290	213	265	181
1200	355	143	225	137	195	124
1100	265	95	155	73	125	76
1000	180	62	92	33	50	38

[a]From 0800 to 1900.

Table 10. Reductions in Cooling Required Due to Change in Roof Surfaces over Perlite; ITCB No. 1 and No. 2, Summer

Line No.	Item	Solar Heat Response	Cooling Required	Solar Heat Response	Cooling Required	Solar Heat Response	Cooling Required	Solar Heat Response	Cooling Required
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		Changing Black to Aluminum Gray		Changing Black to Gray Gravel		Changing Black to White Gravel		Changing Black to White	
1	Ordinates from Fig. 41	700	[illegible]	700	[illegible]	700	495	700	495
2	Ordinates from Fig. 41	461	[illegible]	423	193	307	118	[illegible]	34
3	Recent Reductions	34.1%	[illegible]	39.6%	61.0%	56.1	[illegible]	89.2%	93.1
				Changing Aluminum Gray to Gray Gravel		Changing Aluminum Gray to White Gravel		Changing Aluminum Gray to White	
1	Ordinates from Fig. 41			500	507	500	507	500	507
2	Ordinates from Fig. 41			457	437	334	267	83	30
3	Recent Reductions			8.6%	[illegible]	33.2%	47.3%	83.4%	94.1%
						Changing Gray Gravel to White Gravel		Changing Gray Gravel to White	
1	Ordinates from Fig. 41					500	427	500	427
2	Ordinates from Fig. 41					370	280	93	58
3	Recent Reductions					26.0%	34.4%	81.4%	86.4%

Table 11. Heating Required Due to a Change in Roof Surface from Aluminum Gray to White over Perlite; ITCB No. 1 and No. 2, Winter

Outside Temperature Area[a]	Heating Required from Figure 37(b)			Ratio of White to:	
	White	Gray Gravel	Aluminum Gray	Gray Gravel	Aluminum Gray
(1)	(2)	(3)	(4)	(5)	(6)
900	626	610	540	1.03	1.16
1000	555	538	476	1.03	1.16
1100	483	454	411	1.06	1.18
1200	410	392	347	1.05	1.18
1300	338	321	281	1.05	1.20
1400	257	249	217	1.03	1.18
1500	194	179	152	1.03	1.28
avg	---	---	---	1.05	1.19

[a]From 0000 to 2400.

Table 12. Radiative Cooling Relationships in Urethane/Perlite Built-Up Roofs, All Surfaces; ITCB No. 1 and No. 2, Summer

Outside Temperature Area[a]	Radiative Cooling From Figure 42					Ratio Between Gray Gravel and:			
	Gray Gravel	Aluminum Gray	White Gravel	Black	White	Aluminum Gray	White Gravel	Black	White
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Over Urethane									
3000	105	120	133	142	196	1.14	1.27	1.35	1.87
2900	120	130	140	160	223	1.08	1.17	1.33	1.86
2800	127	135	146	172	237	1.06	1.15	1.35	1.87
2700	129	137	151	177	242	1.06	1.17	1.37	1.88
2600	125	135	155	180	237	1.08	1.24	1.44	1.90
2500	118	127	157	177	225	1.08	1.33	1.50	1.91
2400	107	115	158	171	208	1.07	1.48	1.60	1.94
2300	91	96	158	162	183	1.05	1.74	1.78	2.01
2200	73	68	157	151	148	0.93	2.15	2.07	2.03
avg	---	---	---	---	---	1.06	1.41	1.53	1.92
Over Perlite									
3000	138	137	112	104	207	0.99	0.81	0.75	1.50
2900	145	142	116	123	221	0.97	0.80	0.85	1.52
2800	148	144	119	135	227	0.97	0.80	0.91	1.53
2700	144	142	121	140	226	0.99	0.84	0.97	1.57
2600	136	137	122	143	220	1.01	0.90	1.05	1.62
2500	124	127	121	140	208	1.02	0.98	1.13	1.68
2400	108	111	120	136	190	1.03	1.11	1.26	1.76
2300	90	87	118	129	165	0.97	1.31	1.43	1.83
2200	69	60	115	120	138	0.87	1.67	1.74	2.00
avg	---	---	---	---	---	0.98	1.02	1.12	1.67

[a]From 0000 to 2400.

Table 13. Radiative Cooling Relationships of Urethane to Perlite in Built-Up Roofs; All Surfaces, ITCB No. 1 and No. 2, Summer

Outside Temperature Area[a]	Black			White Gravel			White			Aluminum Gray			Gray Gravel		
	Over Urethane	Over Perlite	Ratio[b]	Over Urethane	Over Perlite	Ratio	Over Urethane	Over Perlite	Ratio	Over Urethane	Over Perlite	Ratio	Over Urethane	Over Perlite	Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
3000	142	104	1.36	133	112	1.19	196	207	0.95	120	137	0.88	105	138	0.76
2900	160	123	1.30	140	116	1.21	223	221	1.01	130	142	0.92	120	145	0.83
2800	172	135	1.27	146	119	1.23	237	227	1.04	135	144	0.94	127	148	0.86
2700	177	140	1.26	151	121	1.25	242	226	1.07	137	142	0.96	129	144	0.90
2600	180	143	1.26	155	122	1.27	237	220	1.08	135	137	0.98	125	136	0.92
2500	177	140	1.26	157	121	1.30	225	208	1.08	127	127	1.00	118	124	0.95
2400	171	136	1.26	158	120	1.32	208	190	1.09	115	111	1.04	107	108	0.99
2300	162	129	1.26	158	118	1.34	183	165	1.11	96	87	1.10	91	90	1.01
2200	151	120	1.26	157	115	1.36	148	138	1.07	68	60	1.13	73	69	1.06
avg	---	---	1.28	---	---	1.27	---	---	1.06	---	---	0.99	---	---	0.92

[a]From 0000 to 2400.

[b]Ratios shown are urethane to perlite.

Figure 1. Insulated temperature controlled building (ITCB)

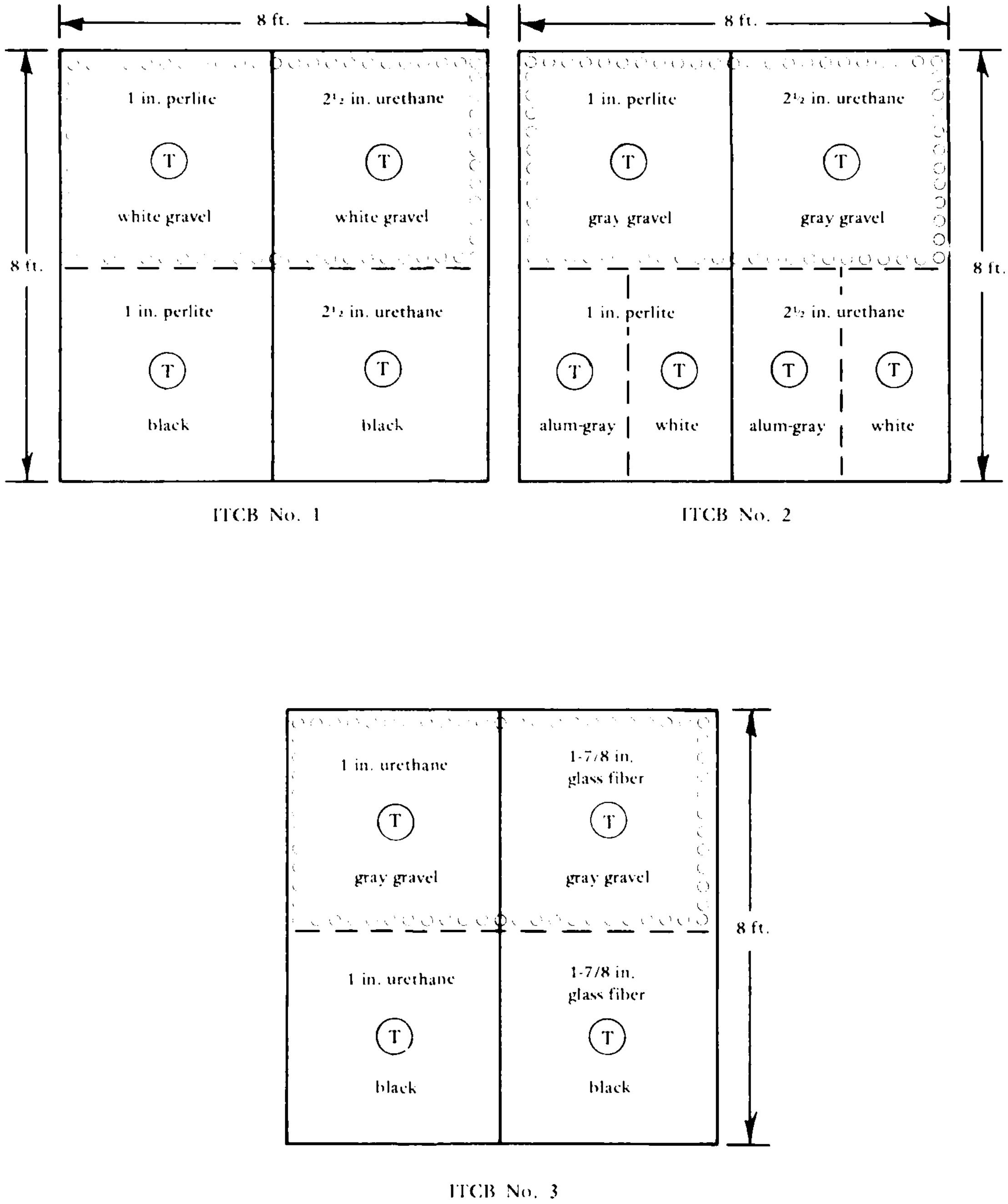


Figure 2. Plan of experimental insulated temperature controlled buildings (ITCB).

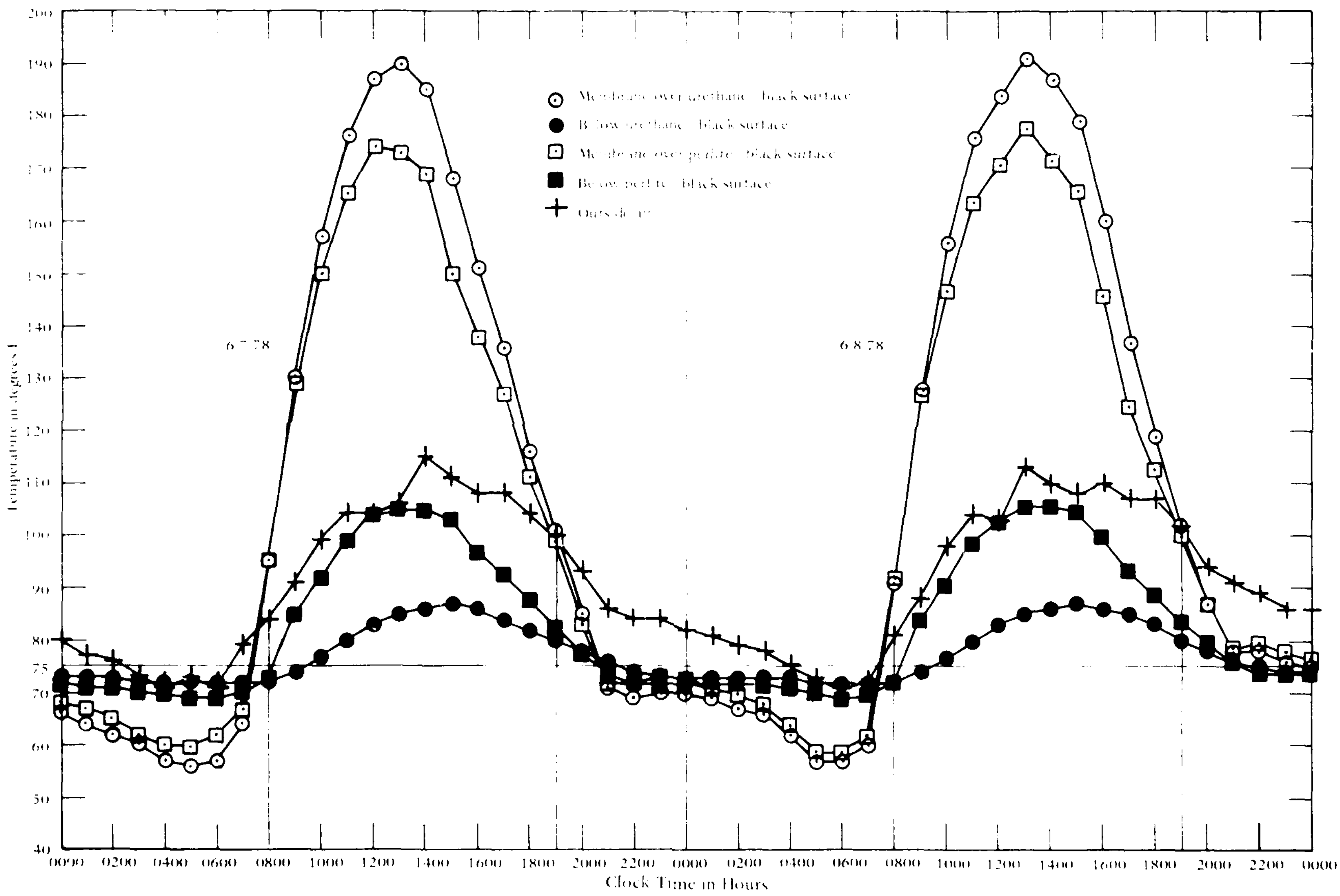


Figure 3. Black surface temperatures in urethane/perlite built-up roof for June 7-8, 1978, HCB No. 1.

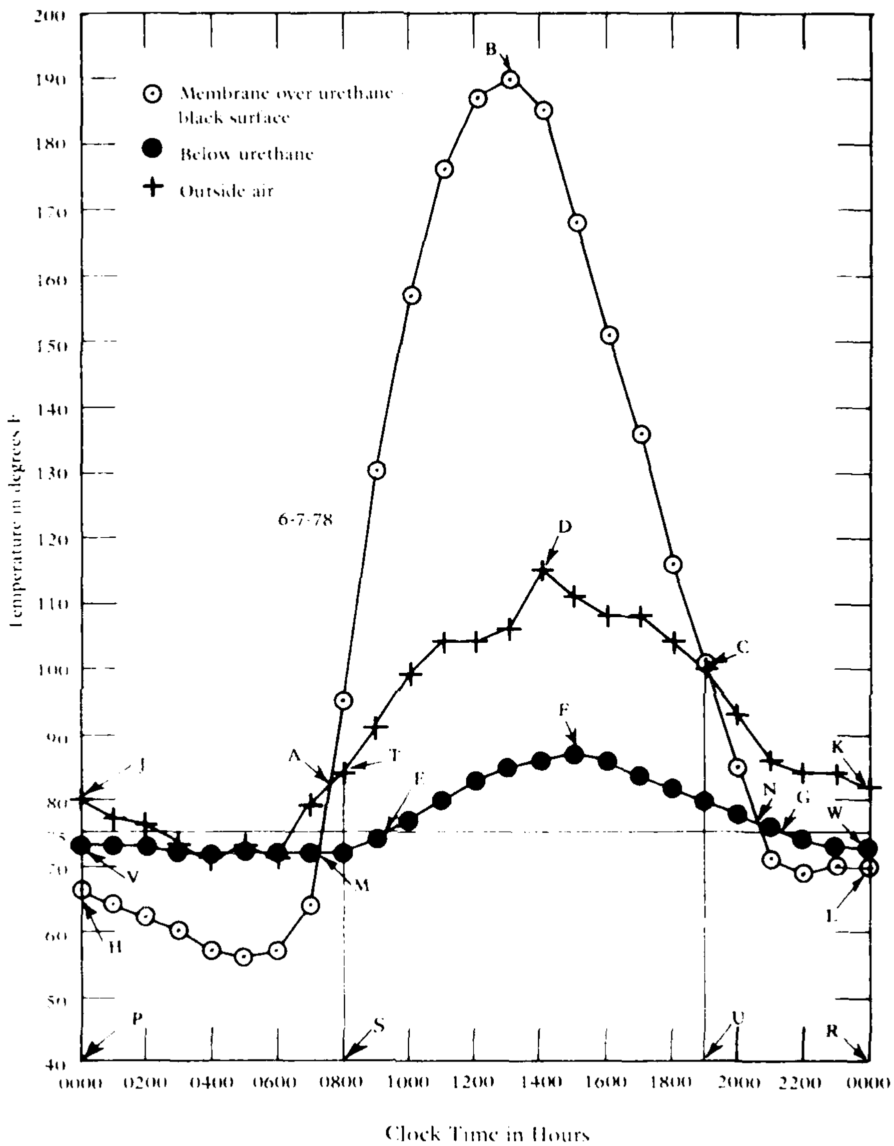
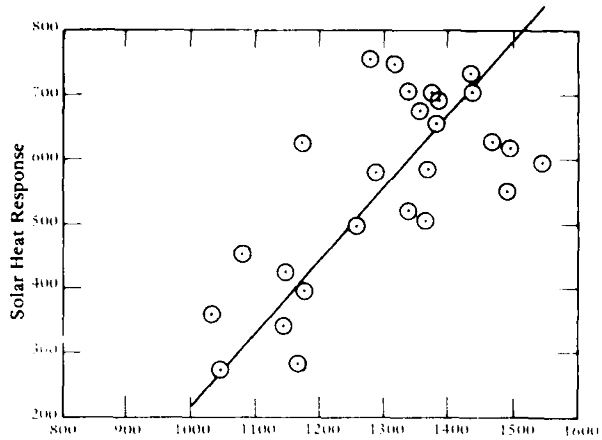
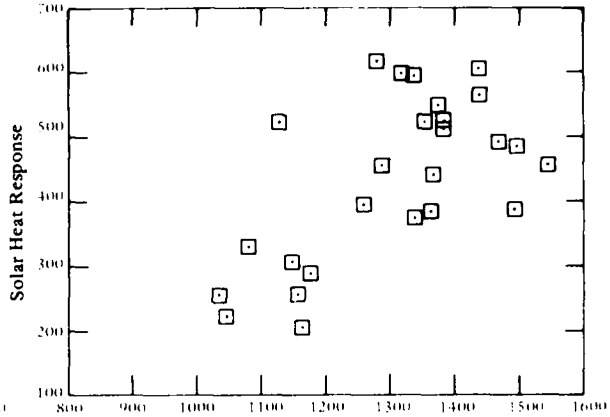


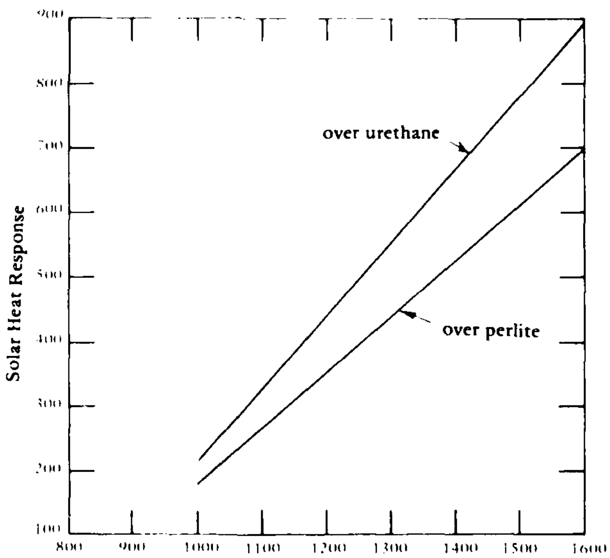
Figure 4. Black surface temperatures with urethane insulation for June 7, 1978, ITCB No. 1.



a. Over urethane.



b. Over perlite.



c. Over urethane and perlite.

Figure 5. Solar heat response in urethane/perlite built-up roof, black surface, ITCB No. 1, summer.

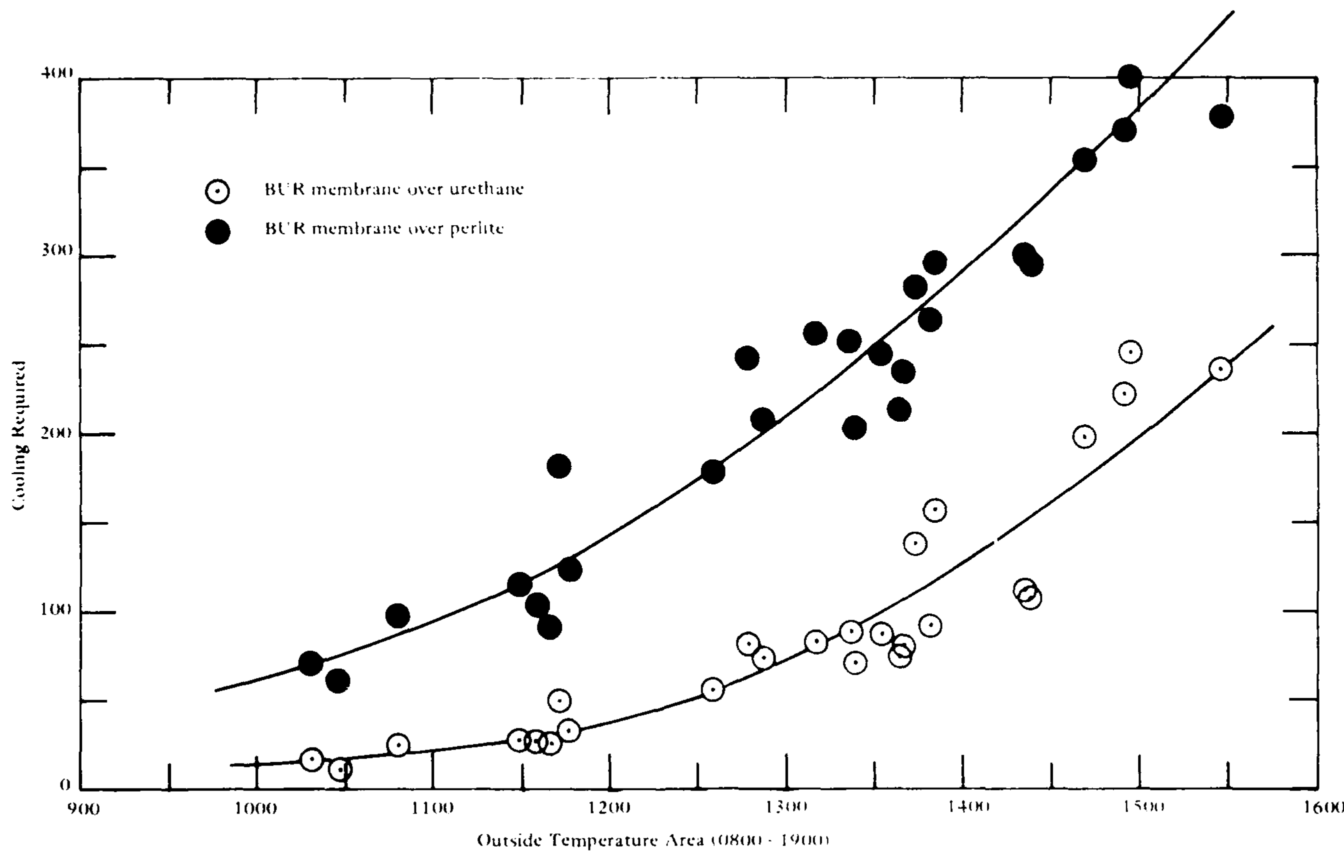
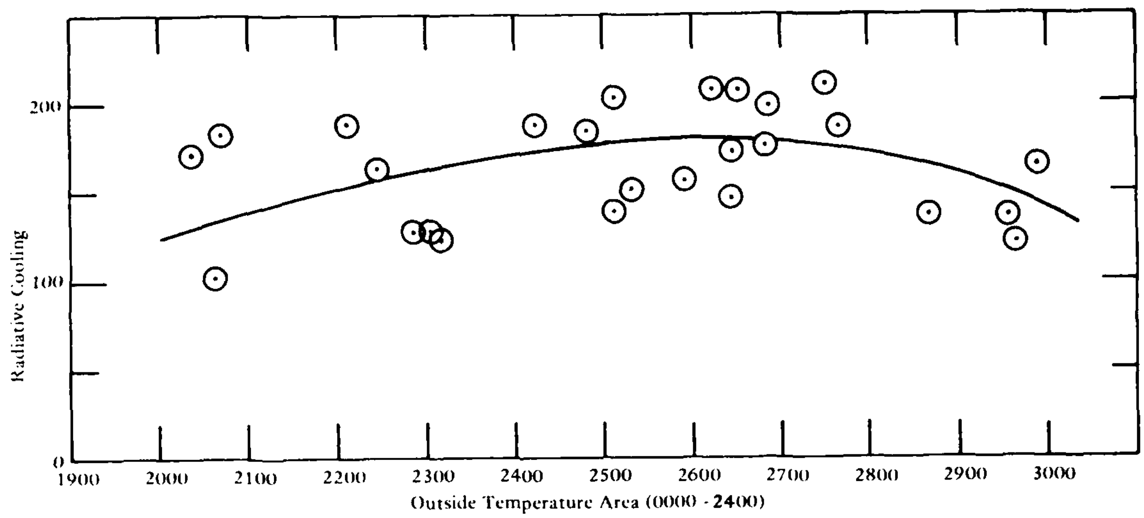
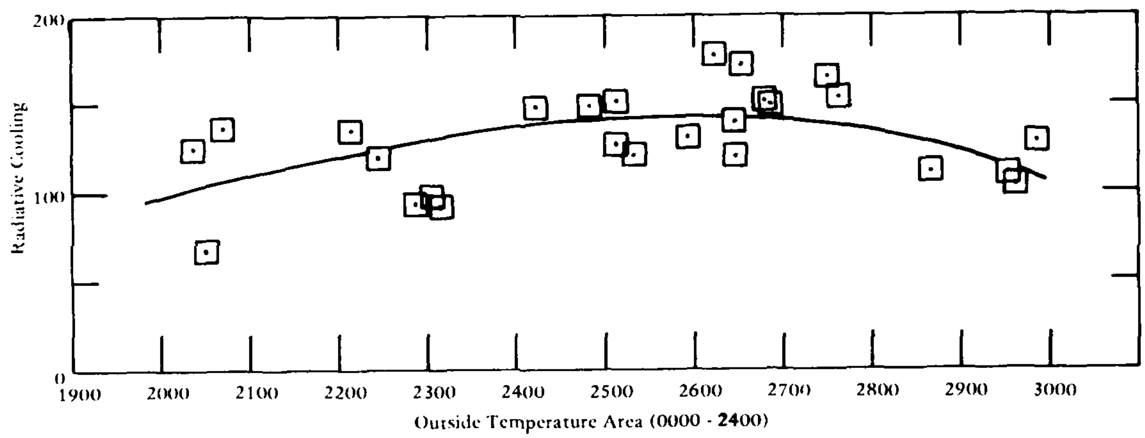


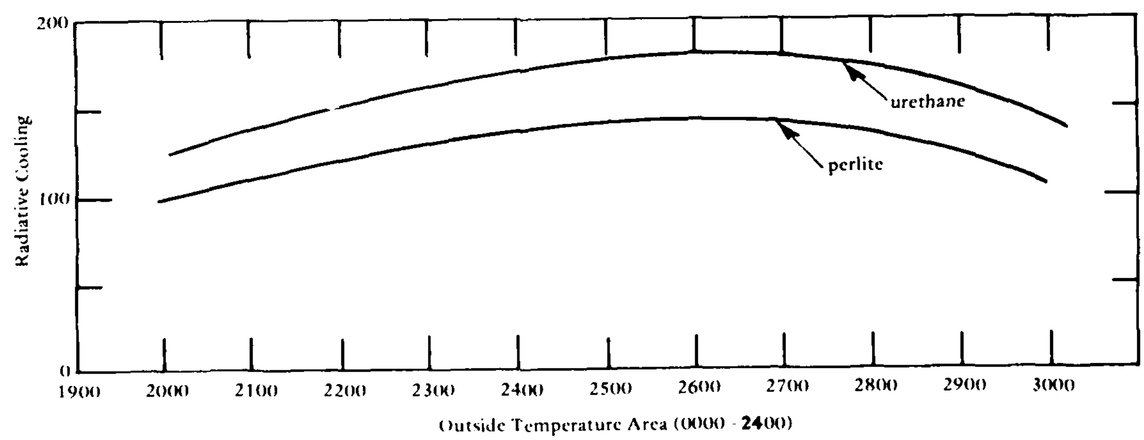
Figure 6. Cooling required in urethane/perlite built-up roof, black surface, FTCB No. 1, summer.



a. Over urethane.



b. Over perlite.



c. Over urethane and perlite.

Figure 7. Radiative cooling in urethane/perlite built-up roof, black surface, ITCB No. 1, summer.

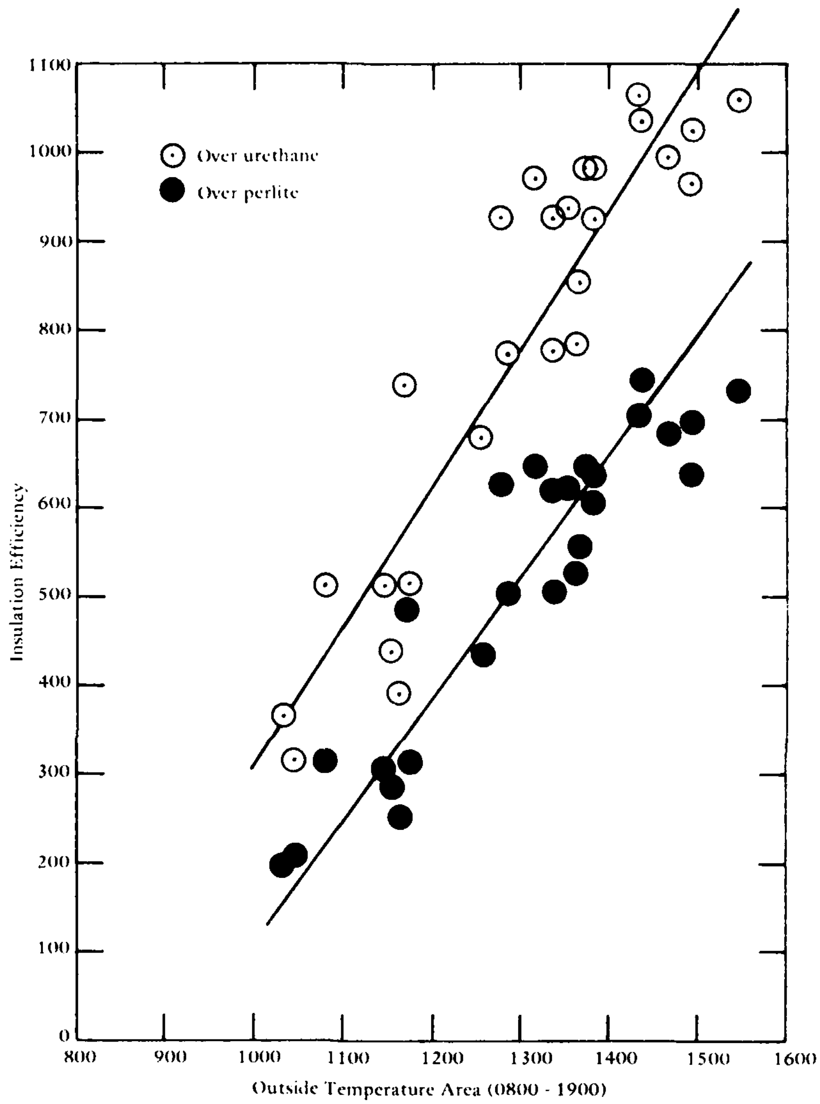


Figure 8. Insulation efficiency in urethane/perlite built-up roof, black surface, ITCB No. 1, summer.

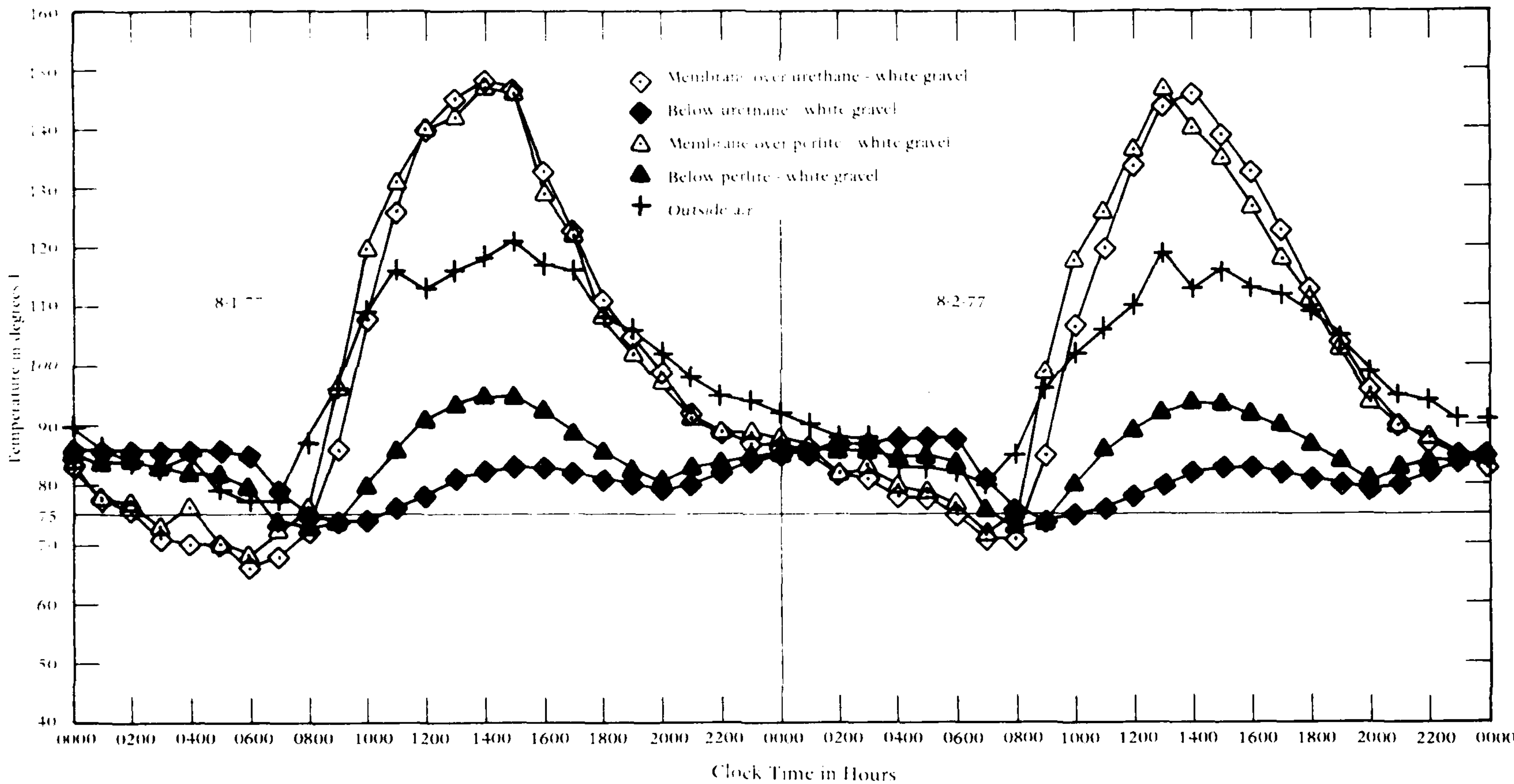
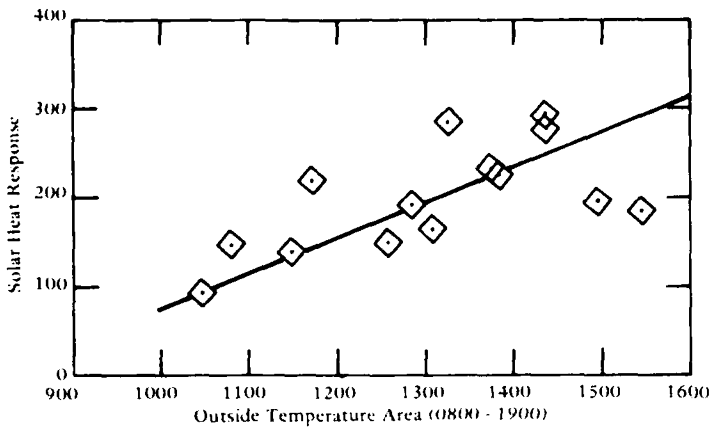
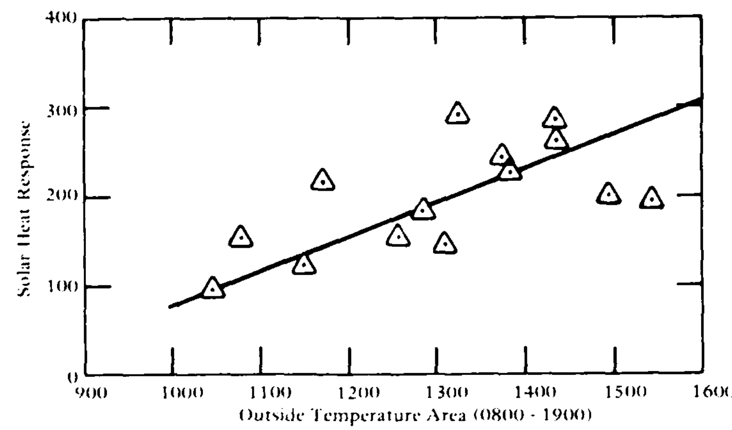


Figure 9. White gravel surface temperatures in urethane/perlite built-up for August 1-2, 1977, ITCB No. 1.



a. Over urethane.



b. Over perlite

Figure 10. Solar heat response in urethane/ perlite built-up roof, white gravel surface, ITCB No. 1, summer.

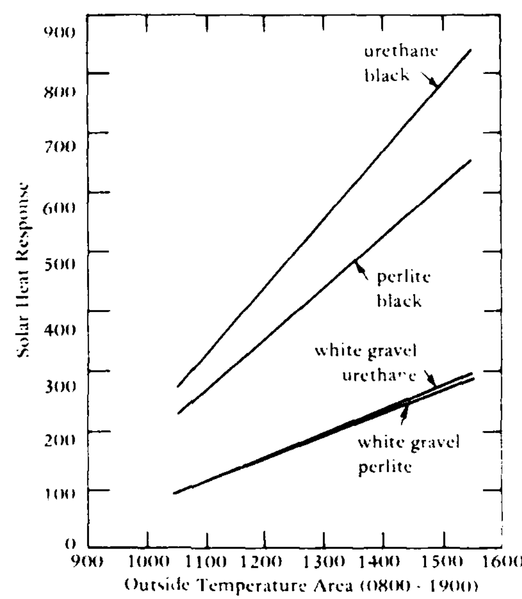
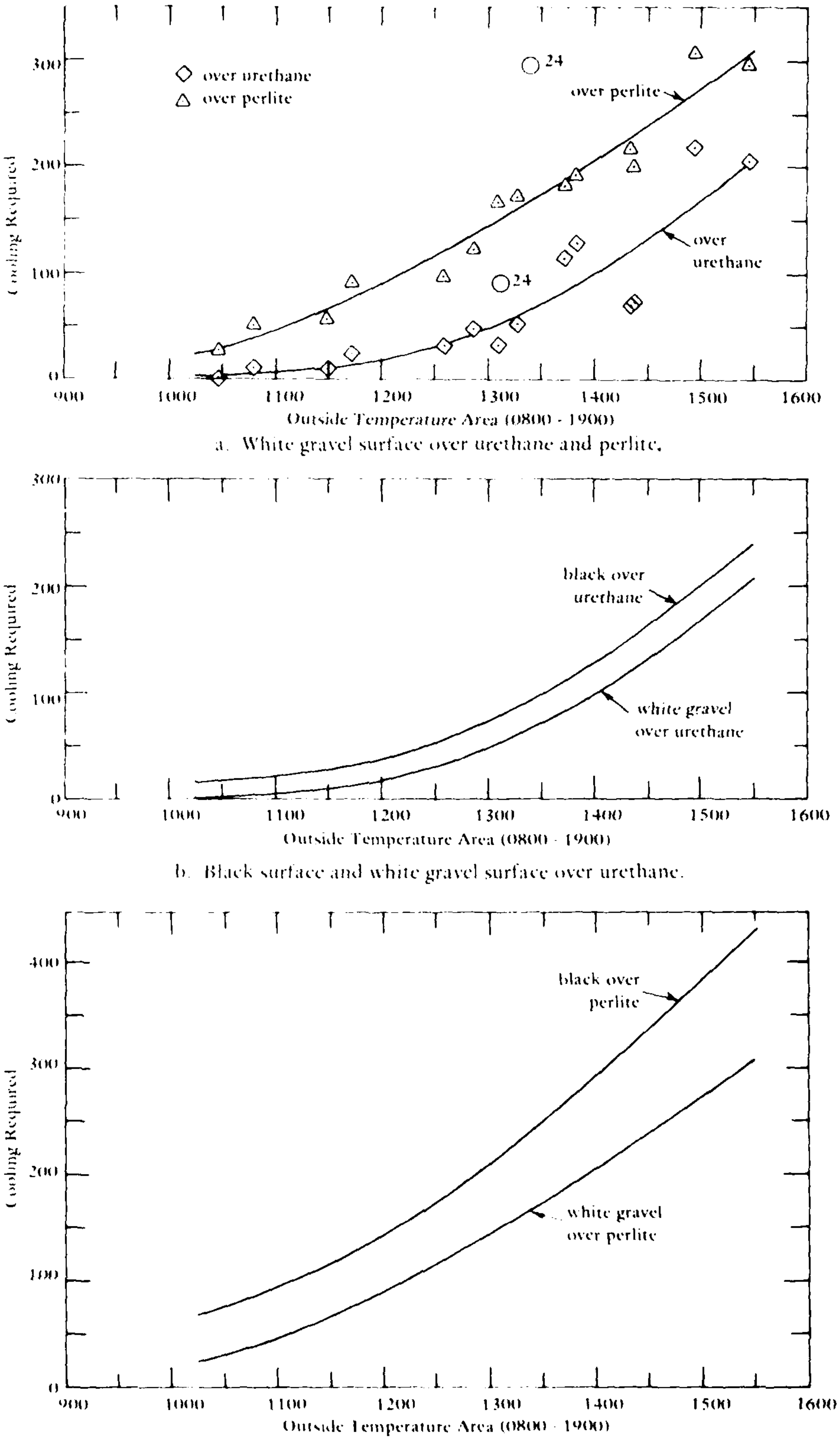


Figure 11. Effects of roof surfacing on solar heat response in urethane/perlite built-up roof, ITCB No. 1, summer.

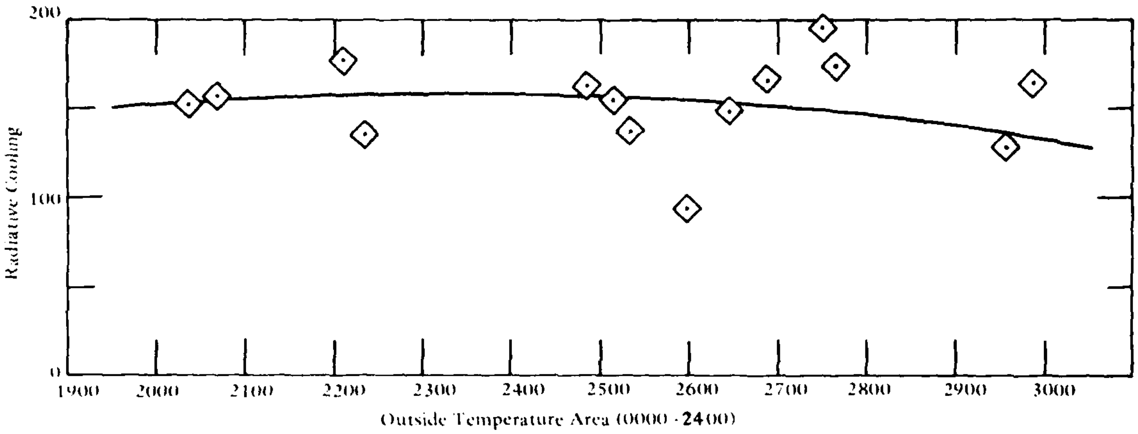


a. White gravel surface over urethane and perlite.

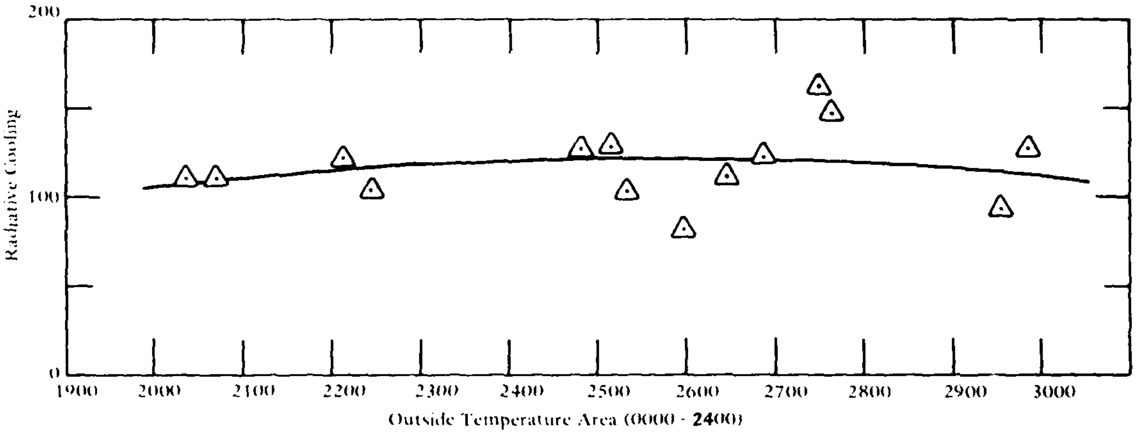
b. Black surface and white gravel surface over urethane.

c. Black surface and white gravel surface over perlite.

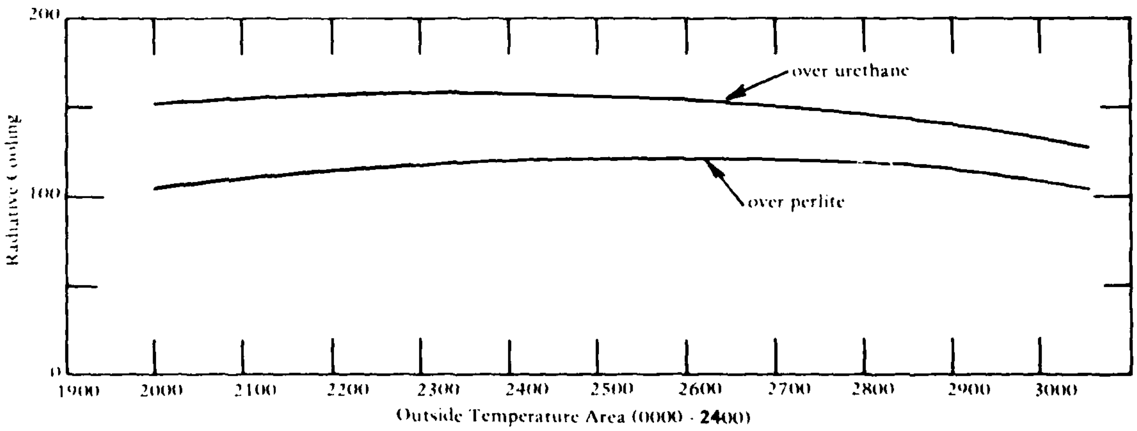
Figure 12. Cooling required in urethane/perlite built-up roof, ITCB No. 1, summer.



a. Over urethane.

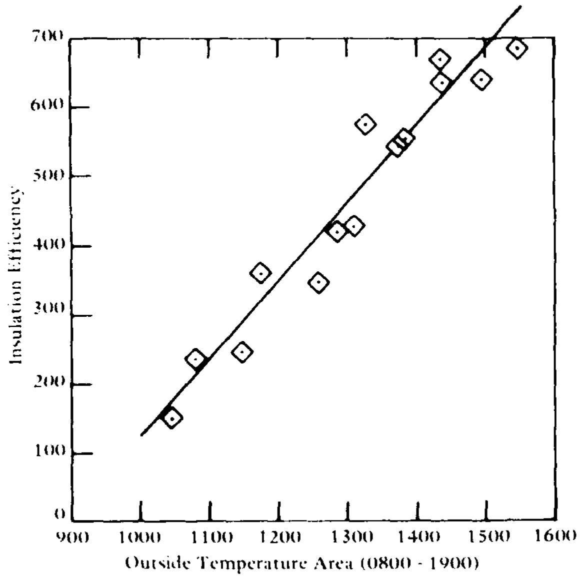


b. Over perlite.

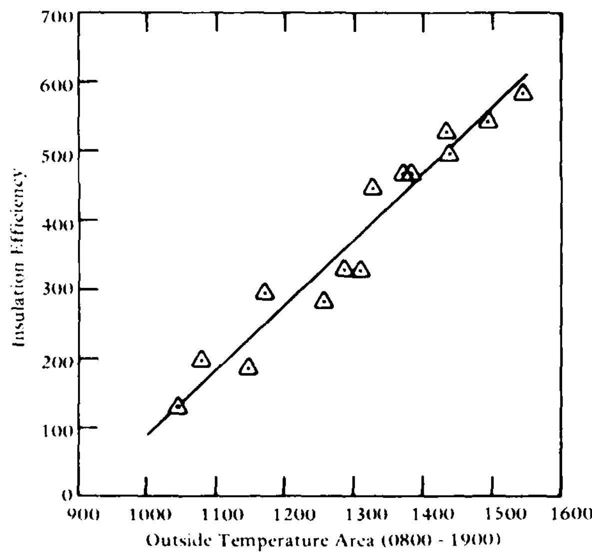


c. Over urethane and perlite.

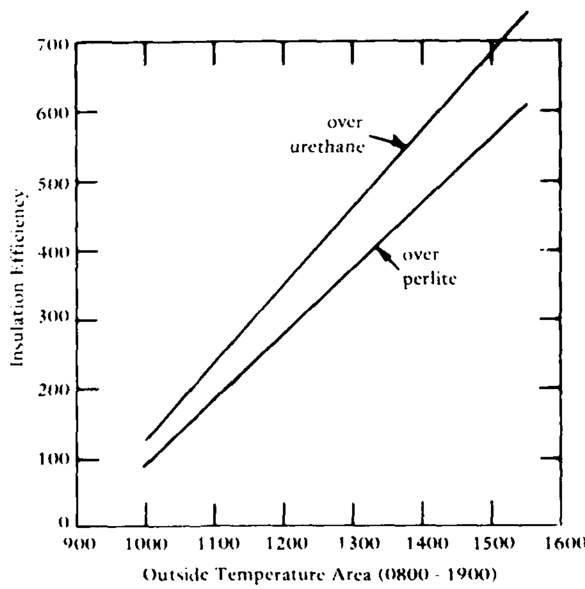
Figure 13. Radiative cooling in urethane/perlite built-up roof, white gravel surface, FTCB No. 1, summer.



a. Over urethane.



b. Over perlite.



c. Over urethane and perlite.

Figure 14. Insulation efficiency in urethane/perlite built-up roof, white gravel surface, ITCB No. 1, summer.

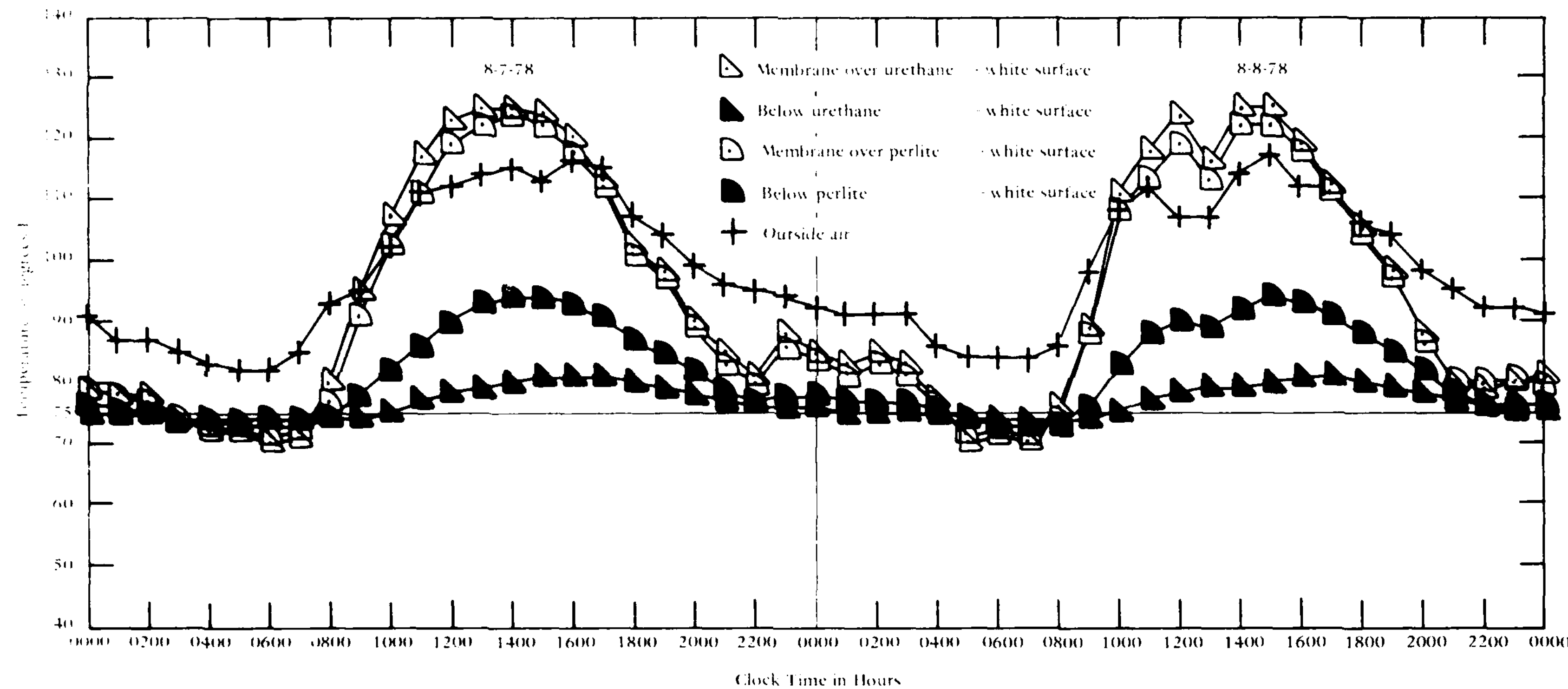


Figure 15. White surface temperatures in urethane/perlite built-up roof for August 7-8, 1978, ITCB No. 2, summer.

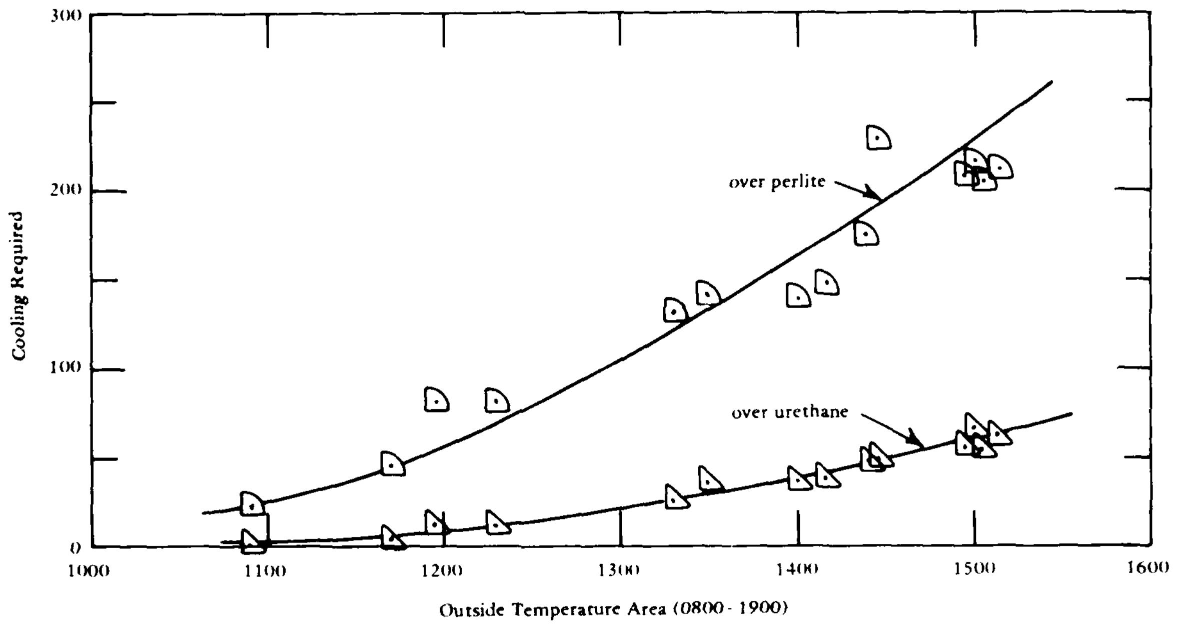
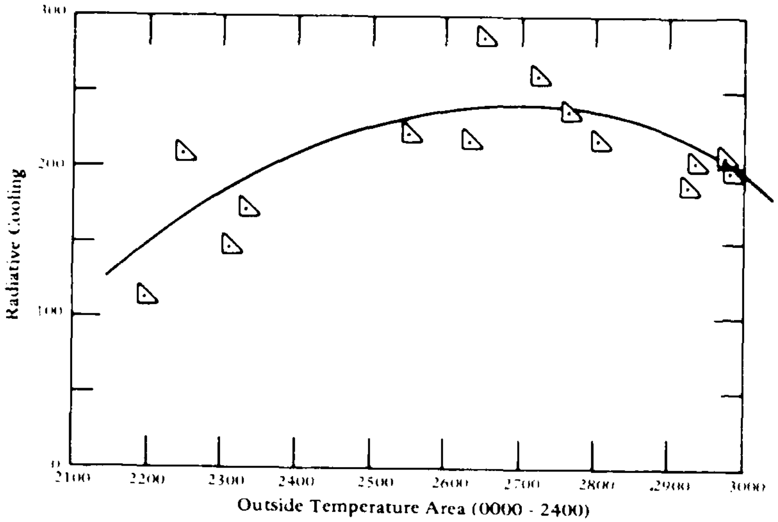
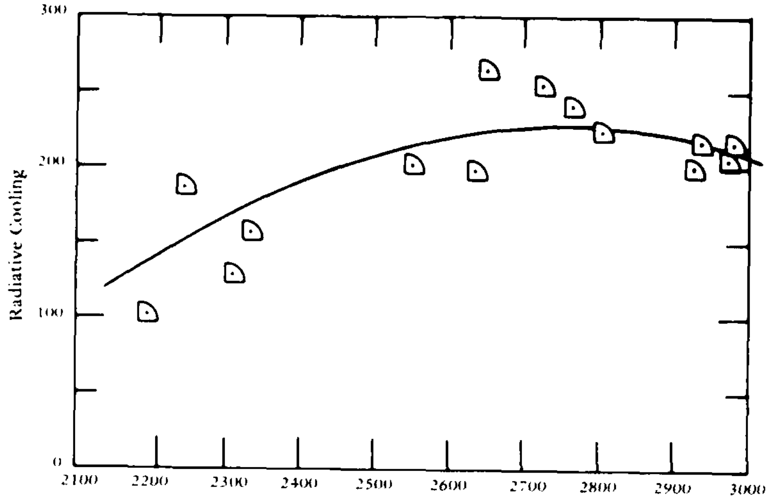


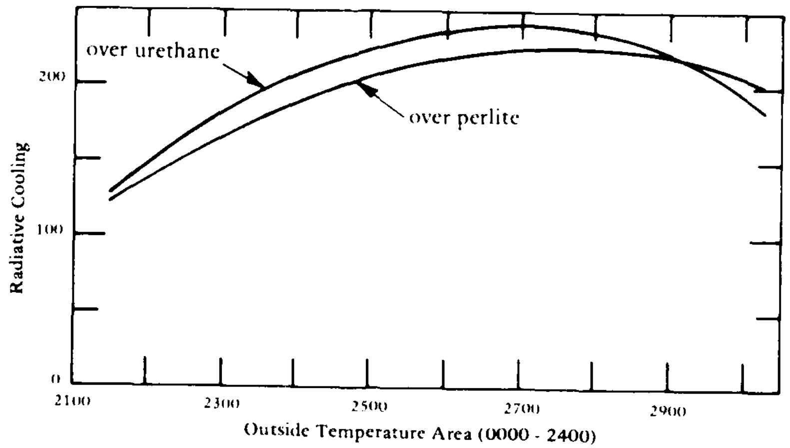
Figure 16. Cooling required in urethane/perlite built - up roof, white surface, ITCB No. 2, summer.



a. Over urethane.



b. Over perlite.



c. Over urethane and perlite.

Figure 17. Radiative cooling in urethane/perlite built - up roof, white surface, ITCB No. 2, summer.

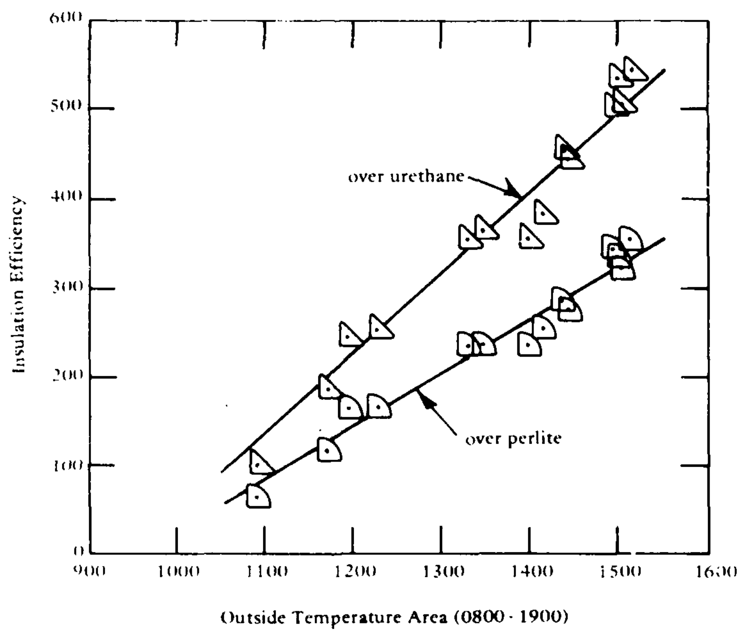


Figure 18 Insulation efficiency in urethane/perlite built-up roof, white surface, ITCB No. 2, summer.

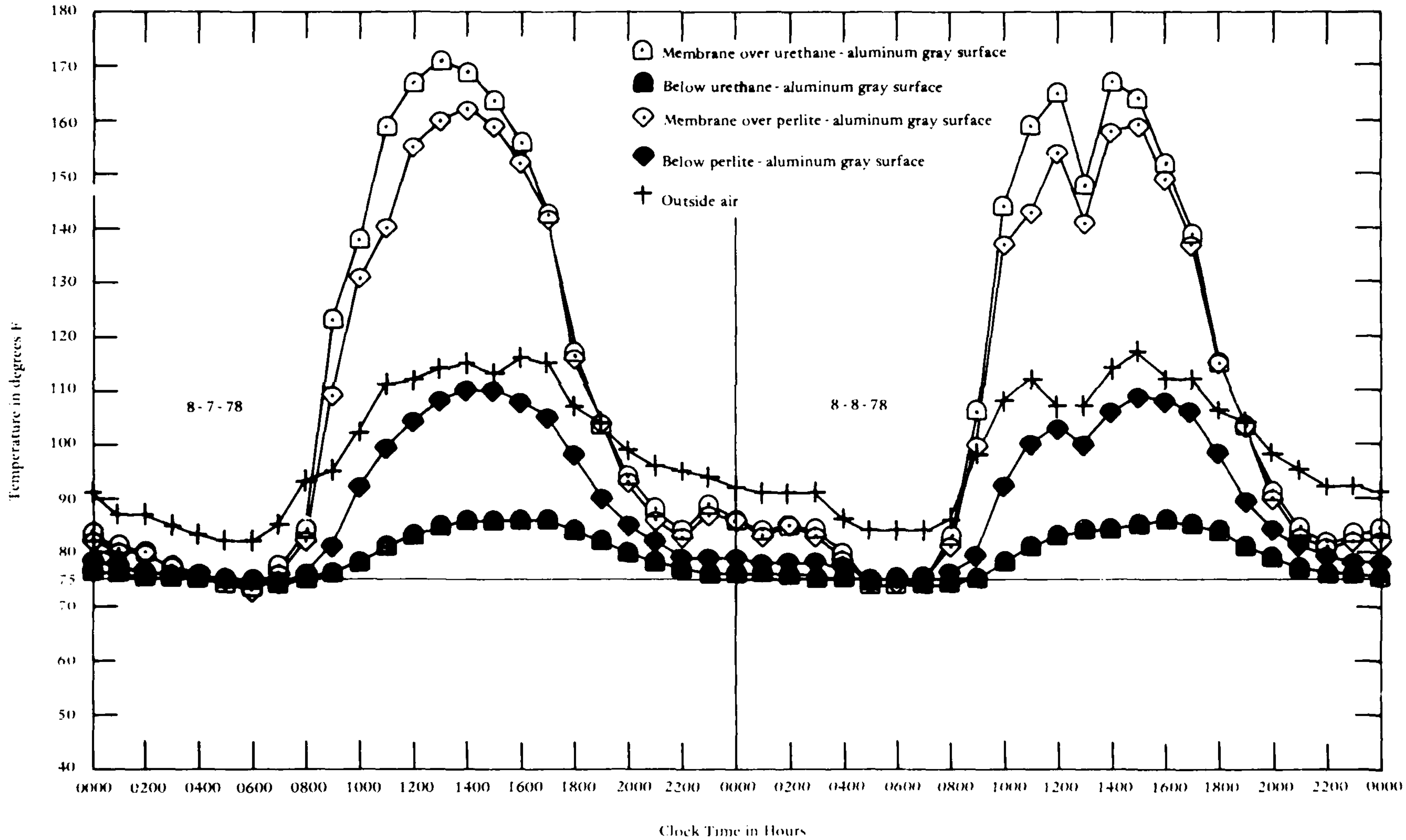
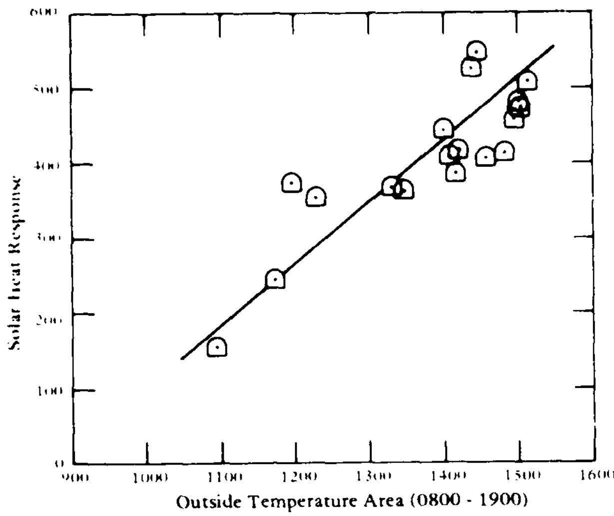
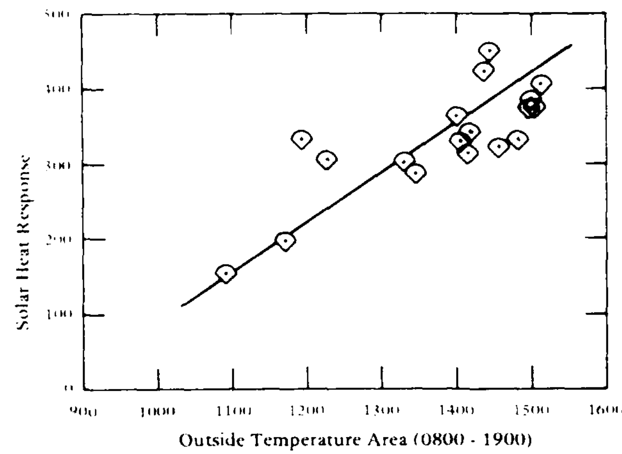


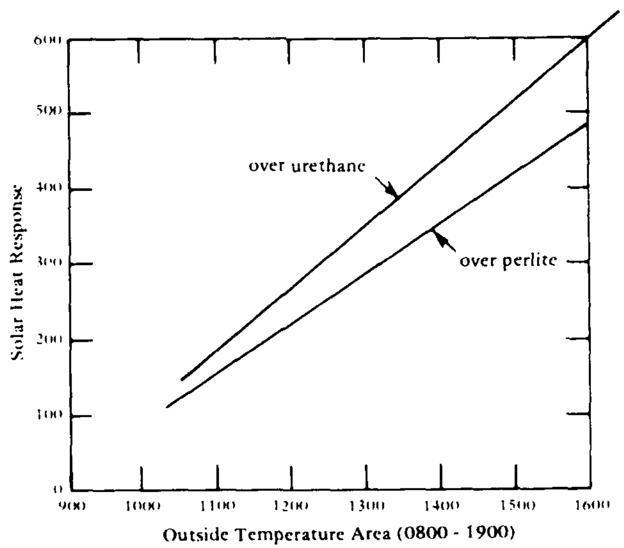
Figure 19. Aluminum gray surface temperatures in urethane/perlite built-up roof for August 7 - 8, 1978, ITCB No. 2.



a. Over urethane.



b. Over perlite.



c. Over urethane and perlite.

Figure 20. Solar heat response in urethane/perlite built-up roof, aluminum gray surface, ITCB No. 2, summer.

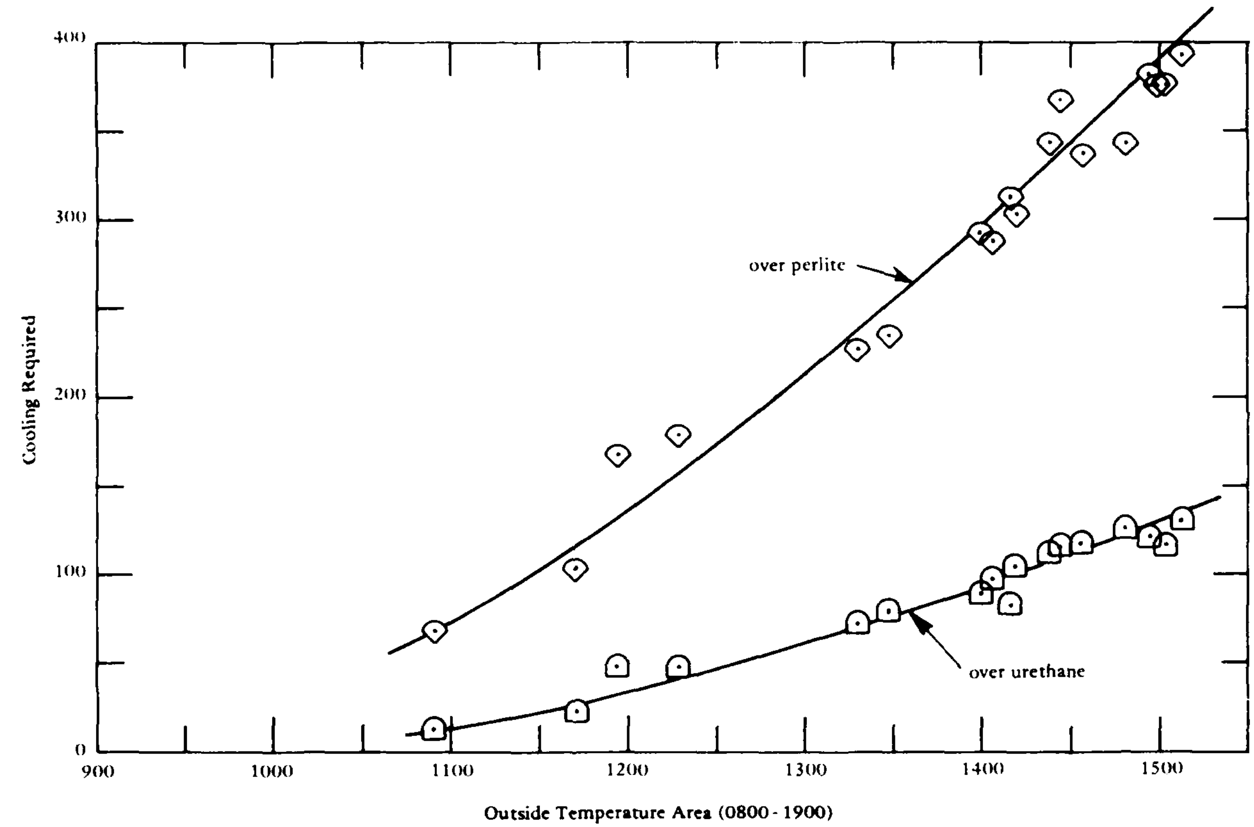
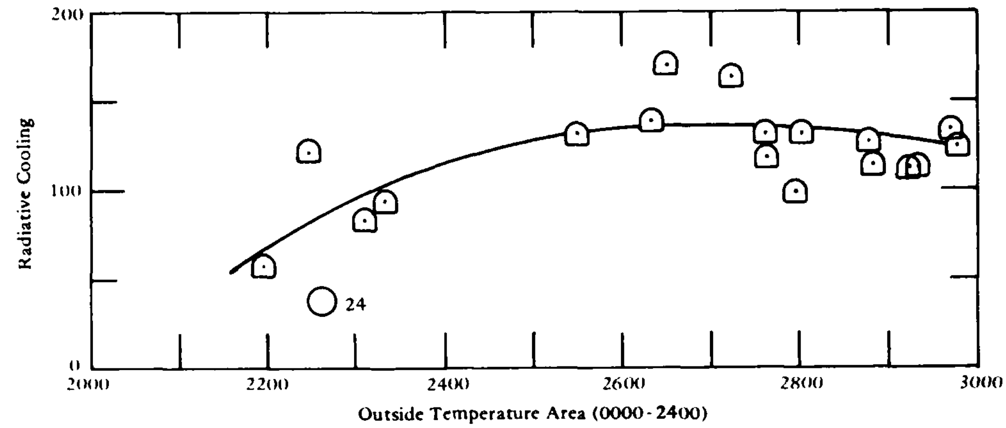
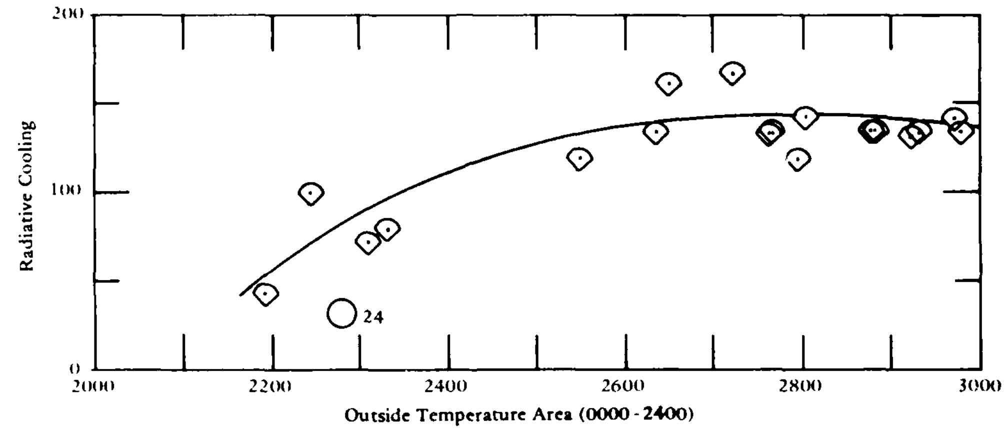


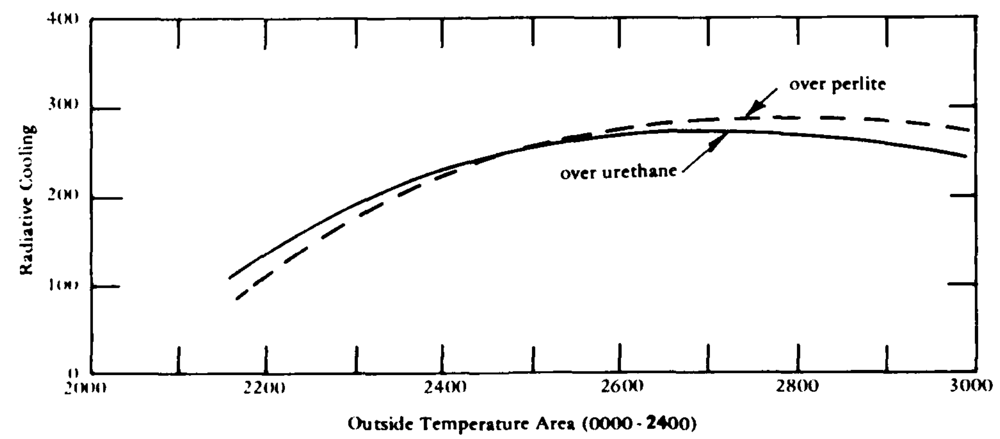
Figure 21. Cooling required in urethane/perlite built - up roof, aluminum gray surface, ITCB No. 2, summer.



(a) Over urethane.



(b) Over perlite.



(c) Over urethane and perlite.

Figure 22. Radiative cooling in urethane/perlite built - up roof, aluminum gray surface, ITCB No. 2, summer.

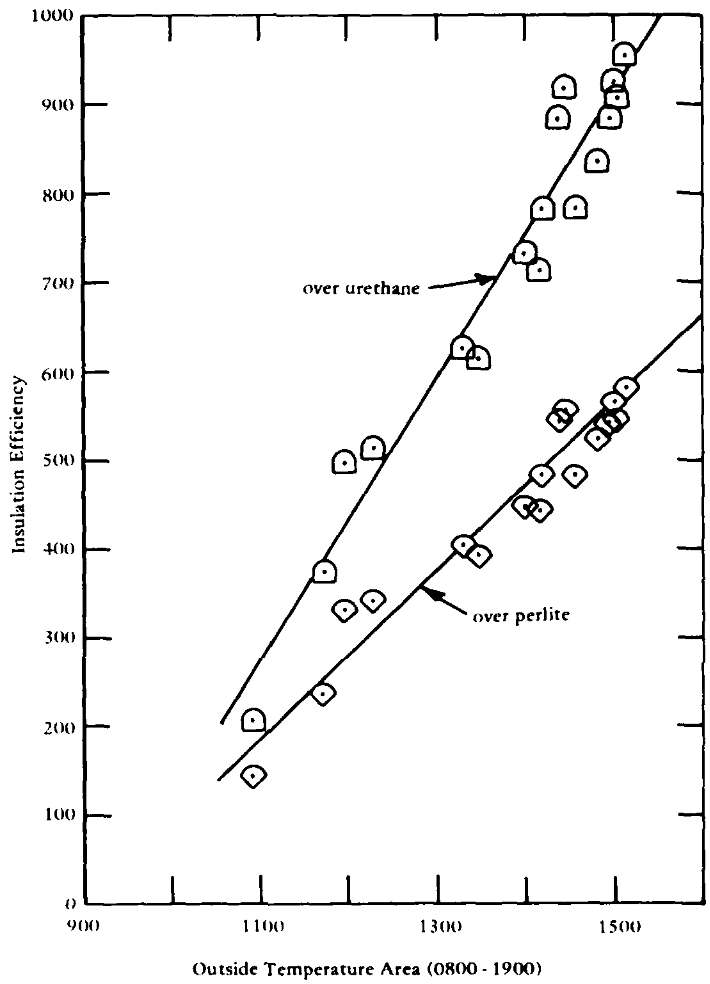


Figure 23. Insulation efficiency in urethane/perlite built-up roof, aluminum gray surface, ITCB No. 2, summer.

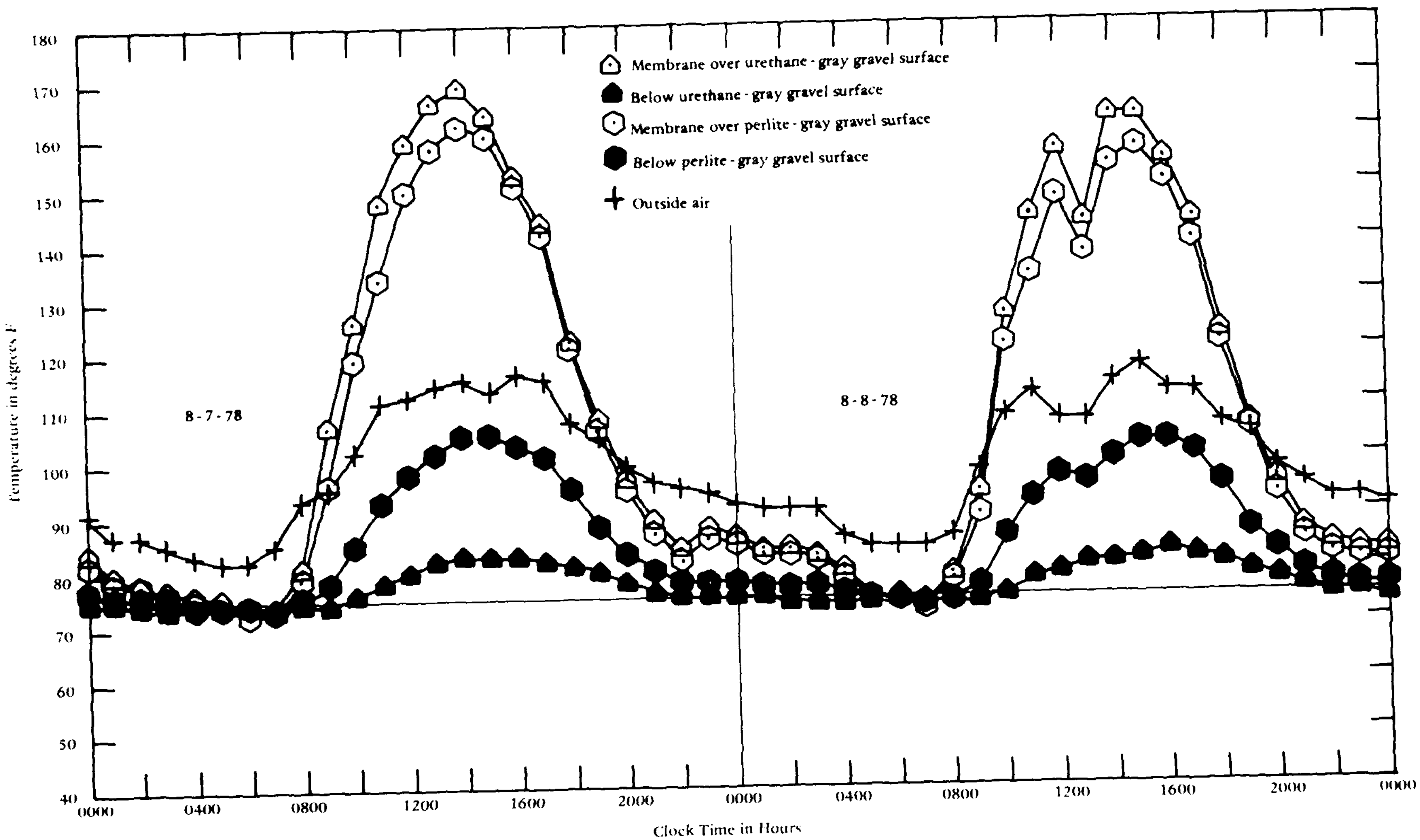
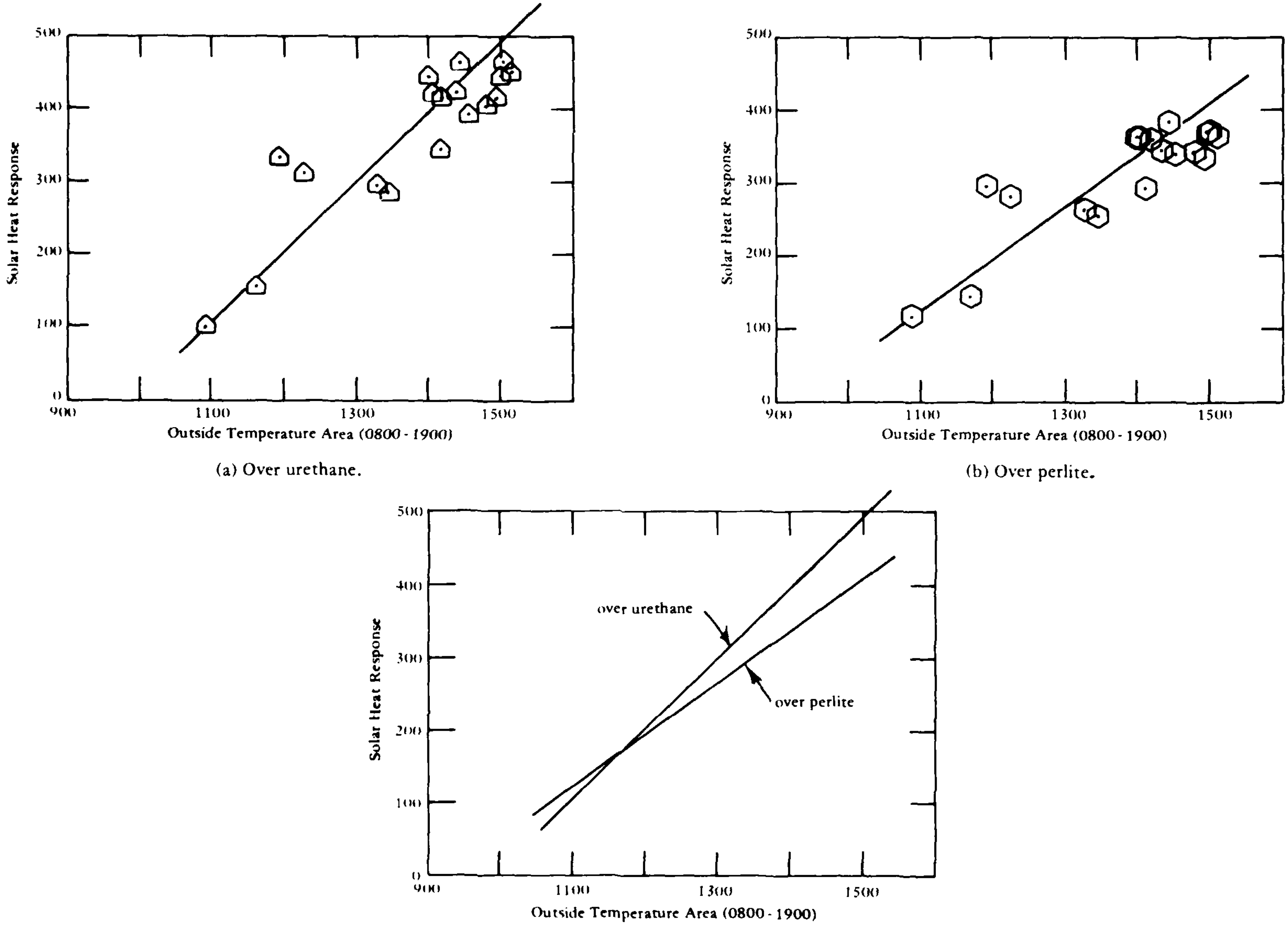


Figure 24. Gray gravel surface temperatures in urethane/perlite built-up roof for August 7 - 8, 1978, ITCB No. 2.

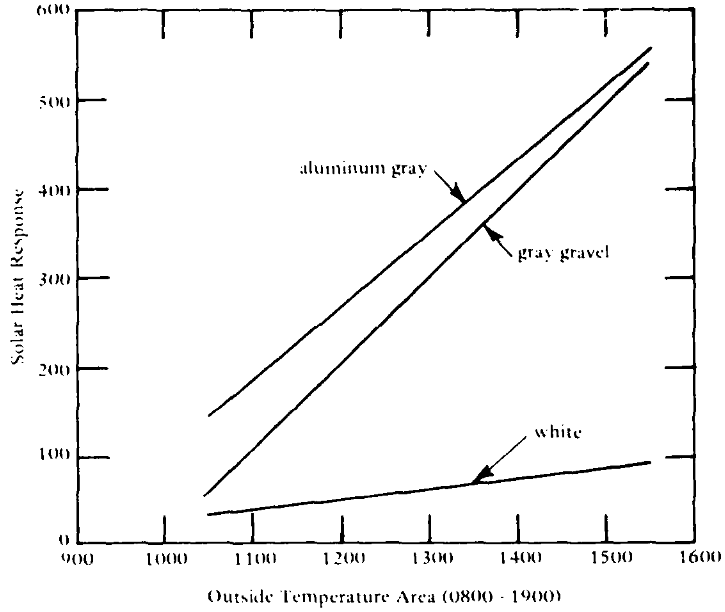


(a) Over urethane.

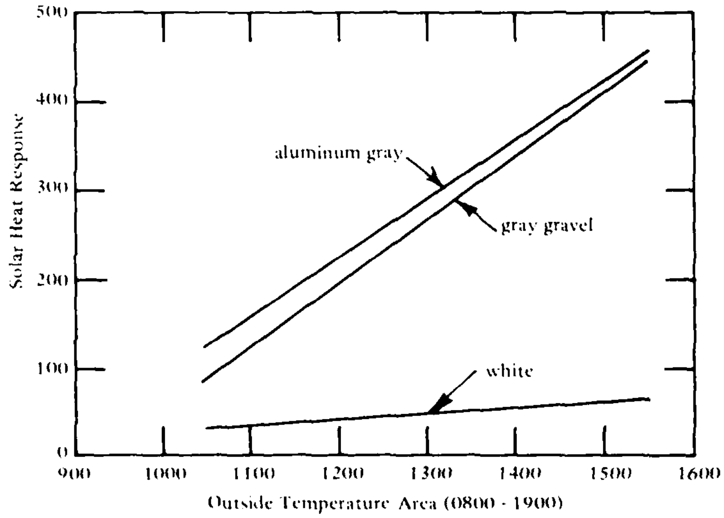
(b) Over perlite.

(c) Over urethane and perlite.

Figure 25. Solar heat response in urethane/perlite built - up roof, gray gravel surface, ITCB No. 2, summer



a. Over urethane.



b. Over perlite.

Figure 26. Solar heat response in urethane/perlite built-up roofs, all surfaces, ITCB No. 2, summer.

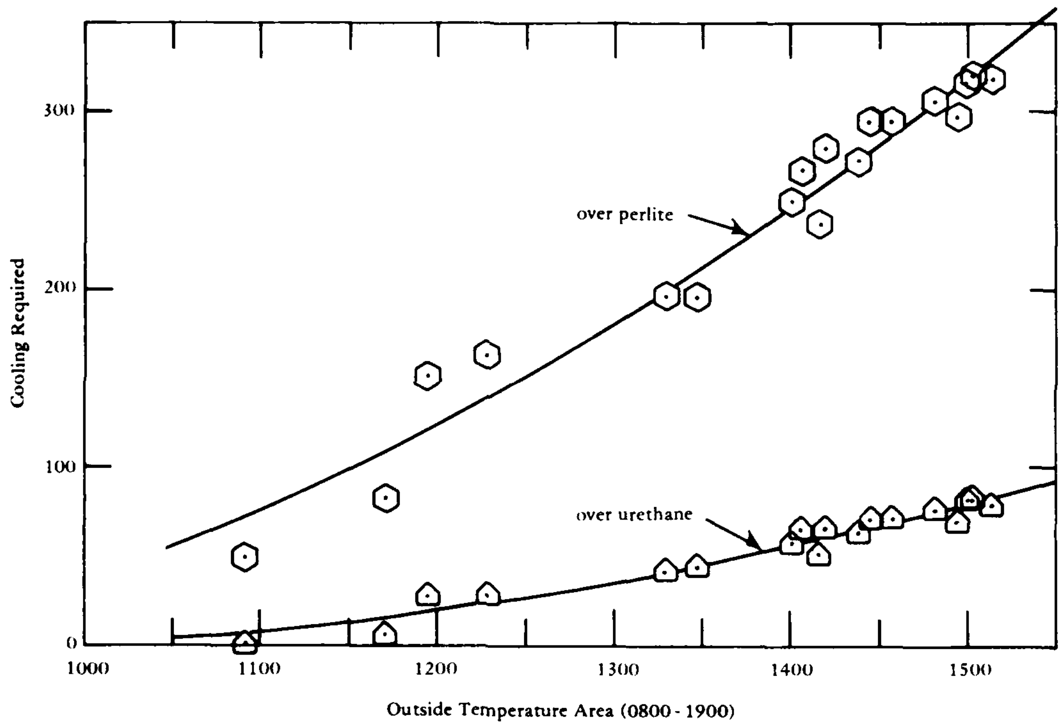
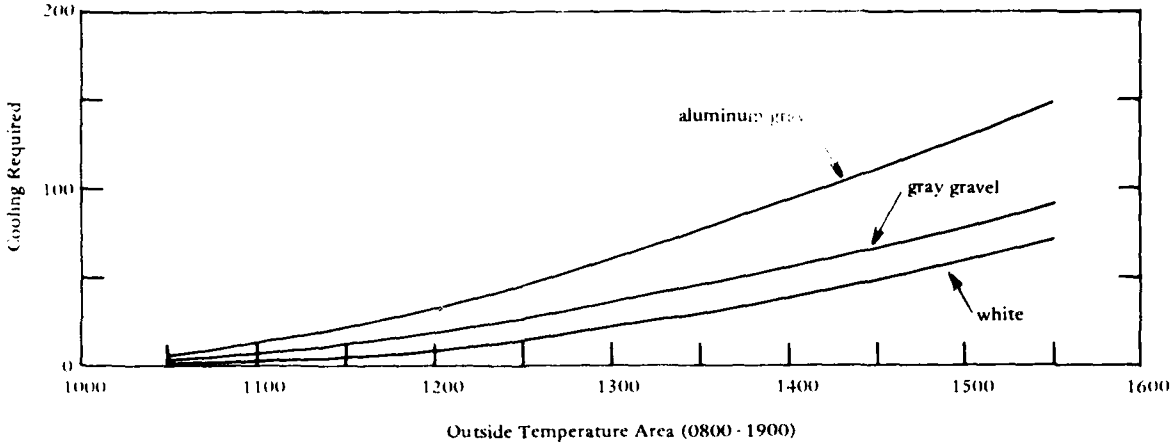
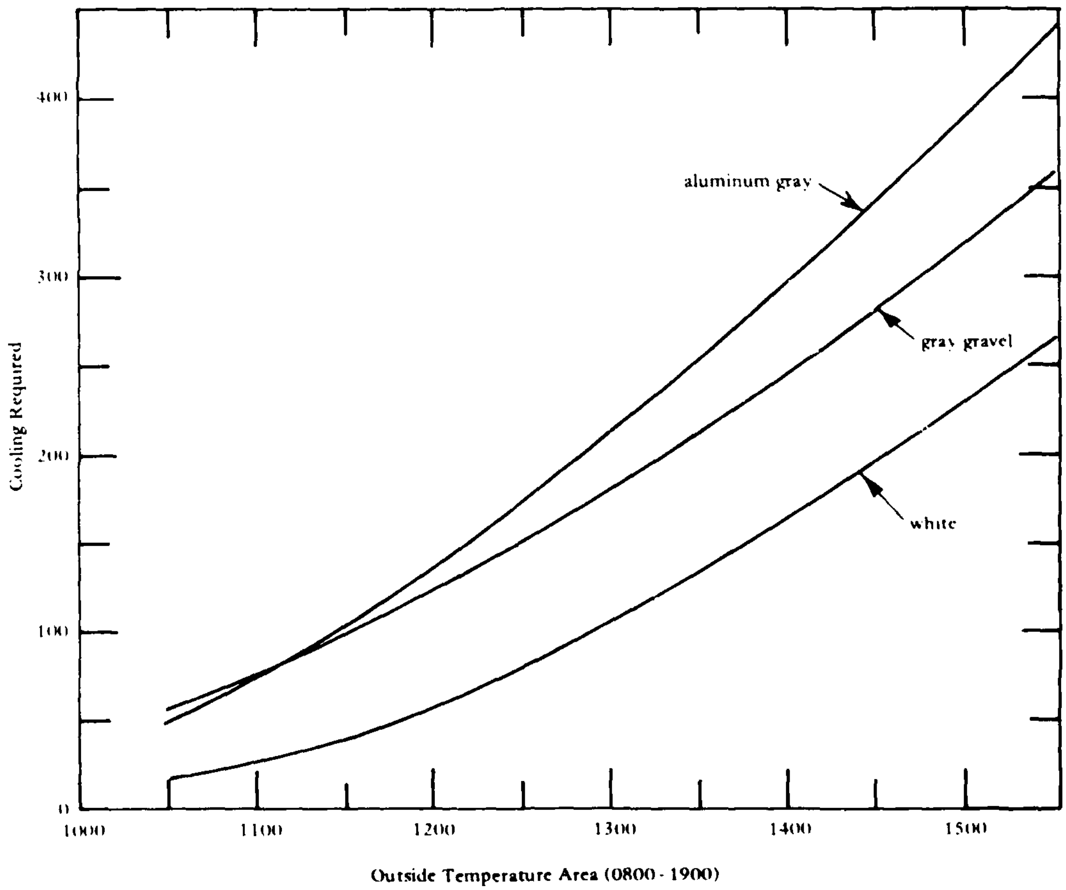


Figure 27. Cooling required in urethane/perlite built - up roof, gray gravel surface, ITCB No. 2, summer.

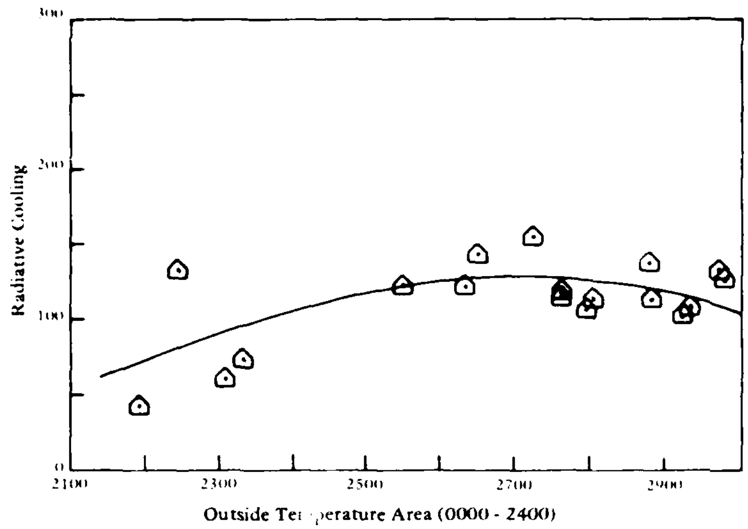


(a) Over urethane

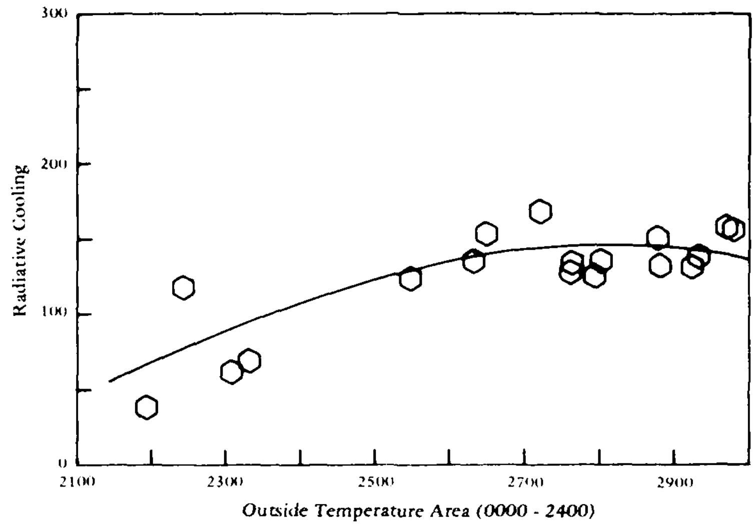


(b) Over perlite

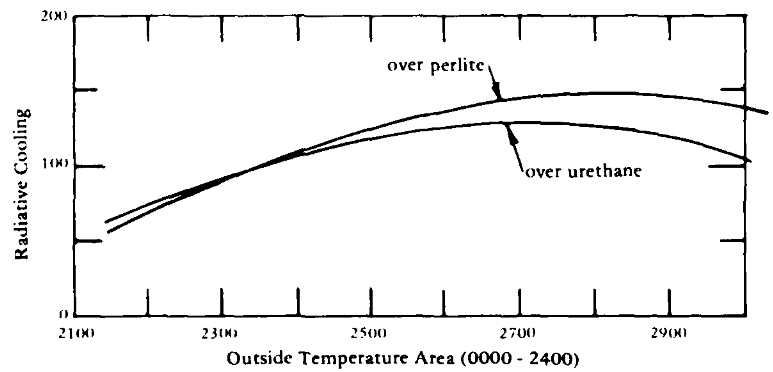
Figure 28. Cooling required in urethane/perlite built-up roofs, all surfaces, ITCB No. 2, summer.



a. Over urethane.

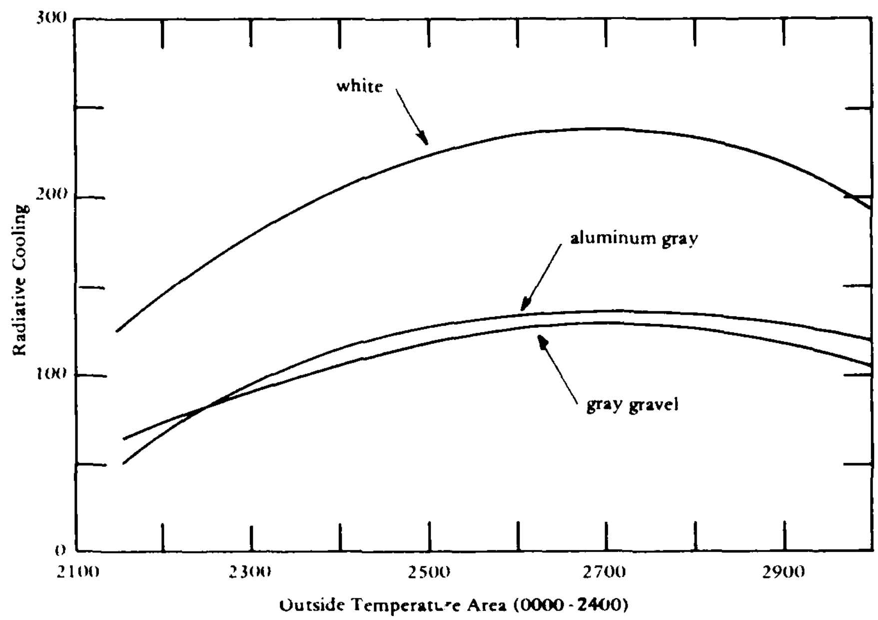


b. Over perlite.

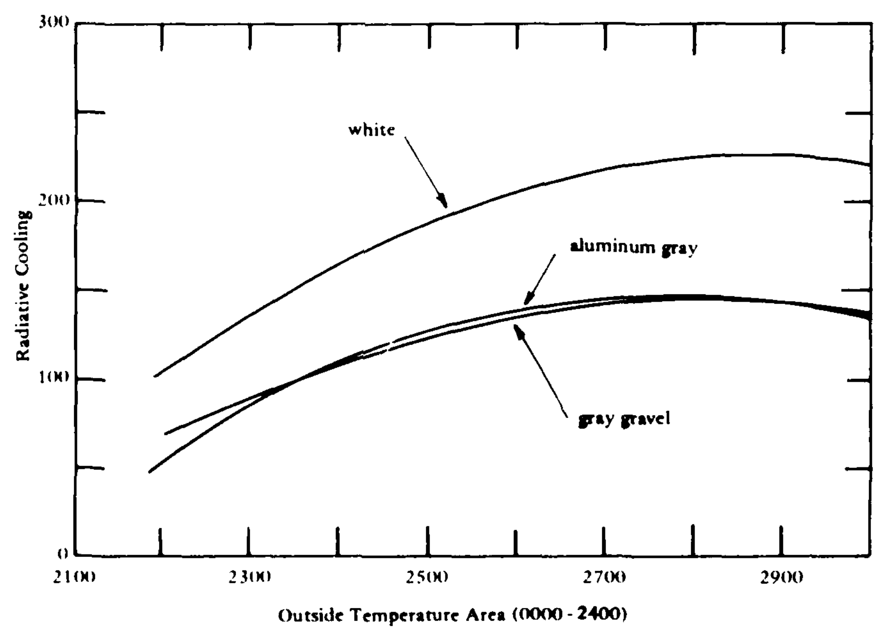


(c) Over urethane and perlite.

Figure 29. Radiative cooling in urethane/perlite built - up roof, gray gravel surface, ITCB No. 2, summer.



(a) Over urethane.



(b) Over perlite.

Figure 30. Radiative cooling in urethane/perlite built-up roof, all surfaces, ITCB No. 2, summer.

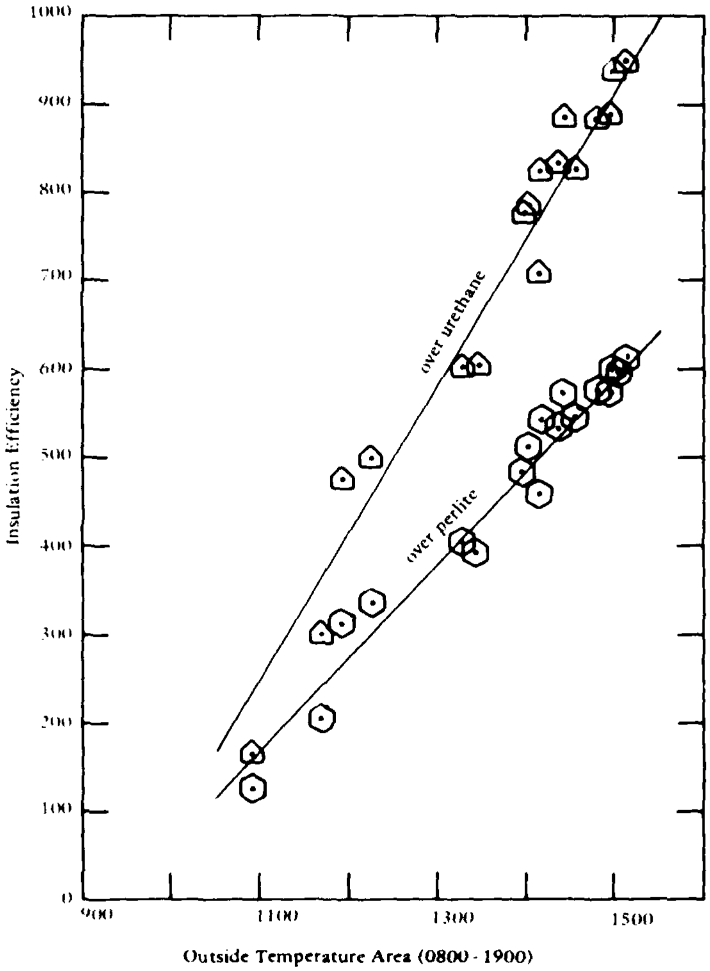


Figure 31. Insulation efficiency in urethane/perlite built - up roof, gray gravel surface, ITCB No. 2, summer.

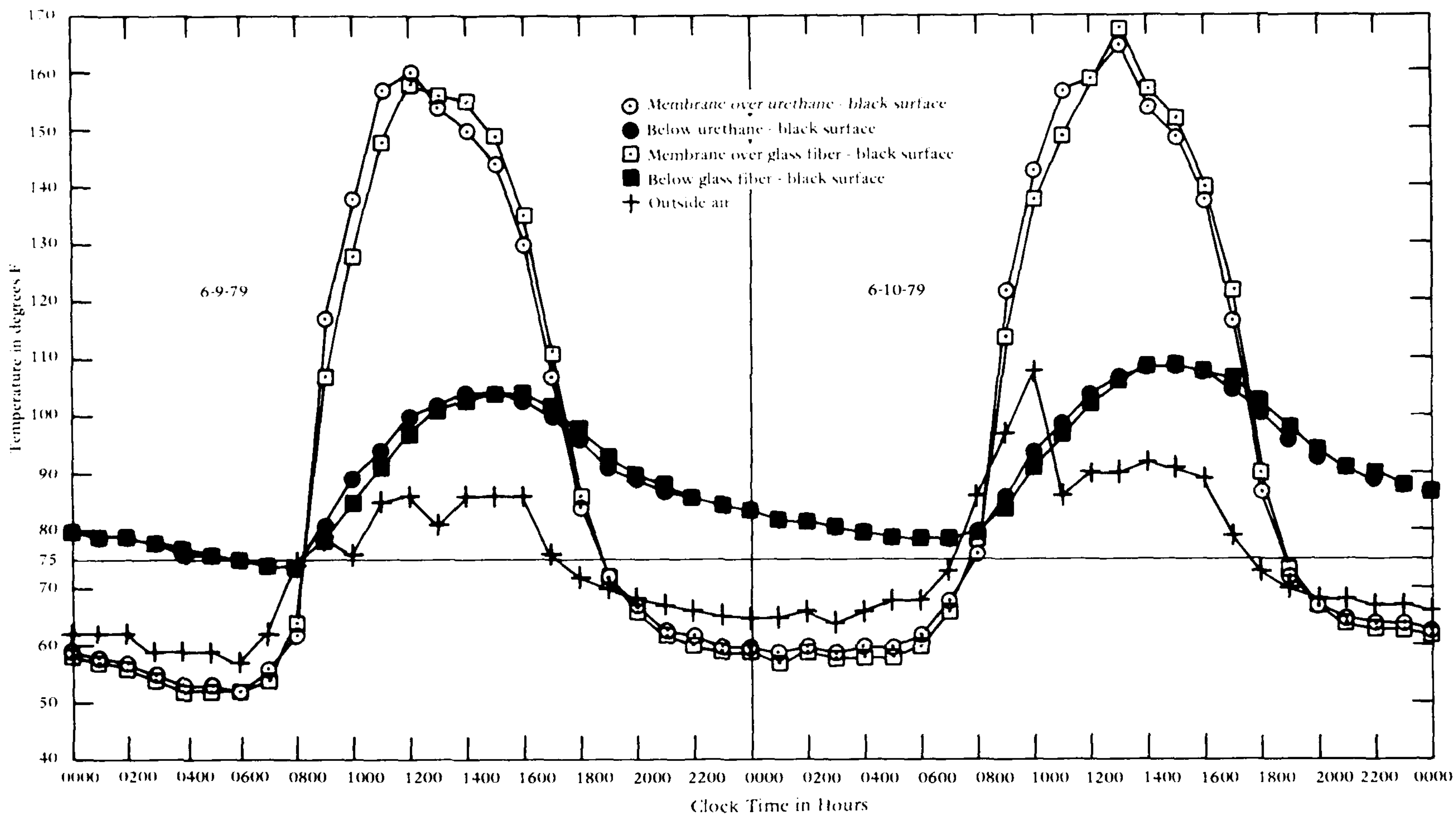


Figure 32. Black surface temperatures in urethane/glass fiber built-up roof for June 9-10, 1979, ITCB No. 3.

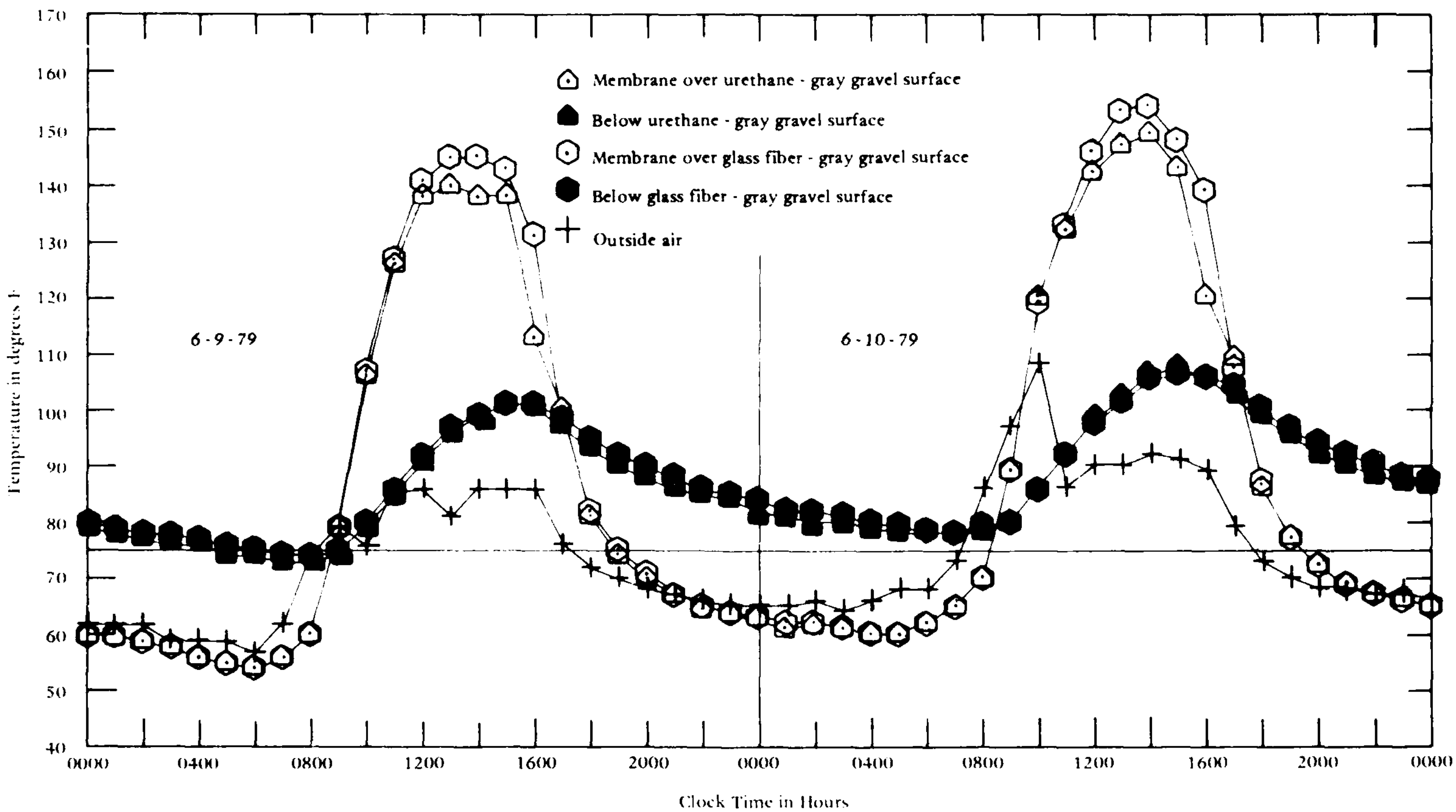


Figure 33. Gray gravel surface temperatures in urethane/glass fiber built-up roof for June 9 - 10, 1979, ITCB No. 3.

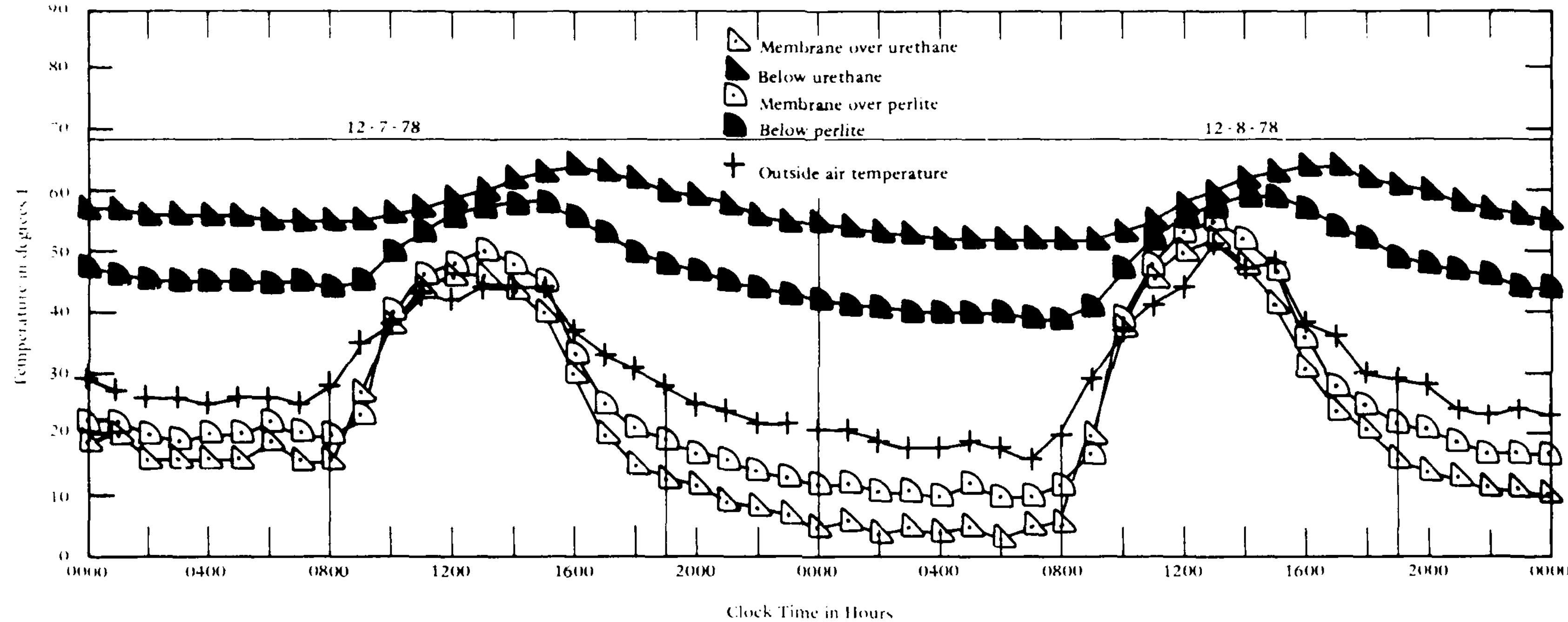


Figure 34. White surface temperatures in urethane/perlite built-up roof for December 7 - 8, 1978, ITCB No. 2.

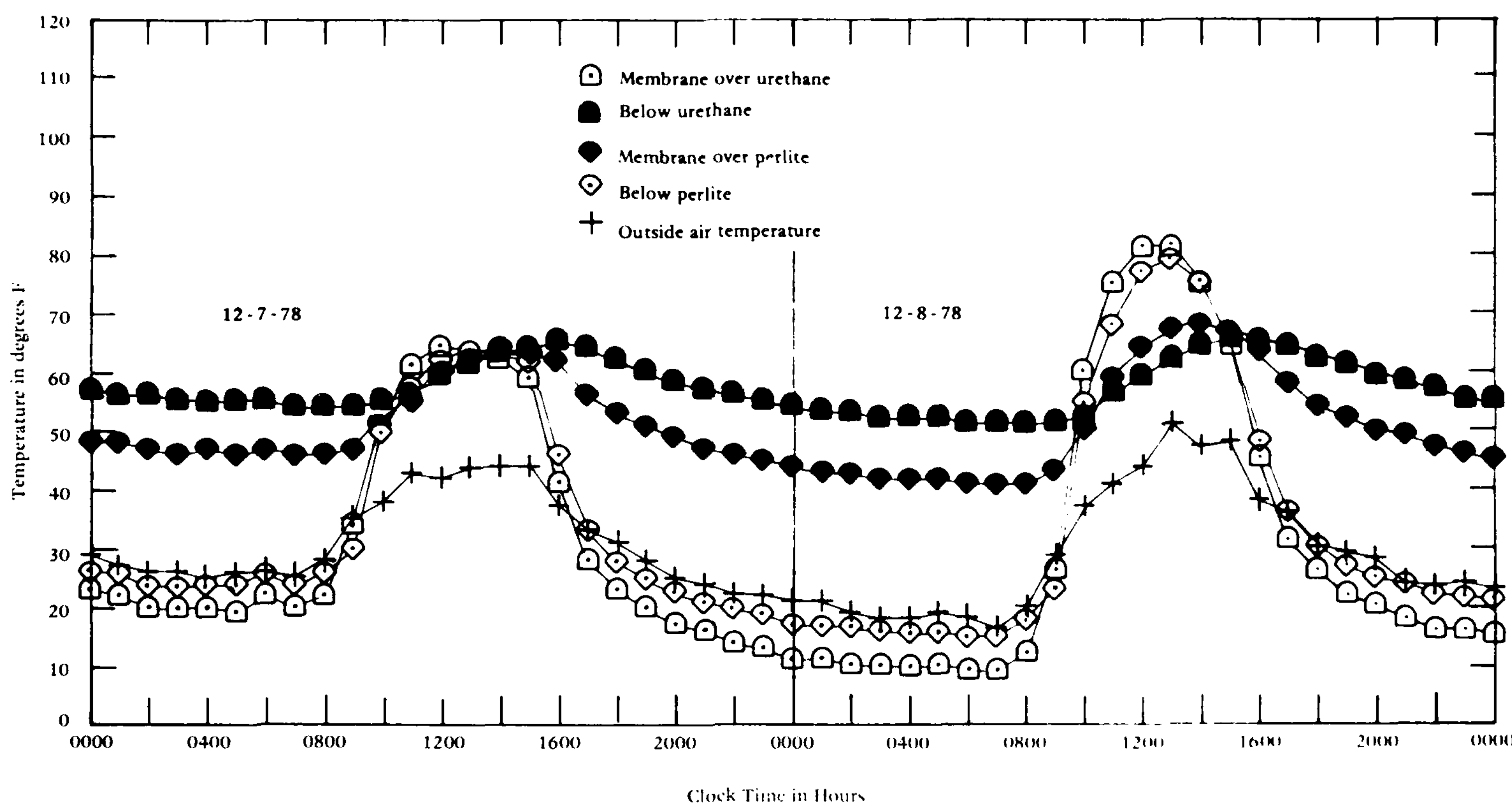
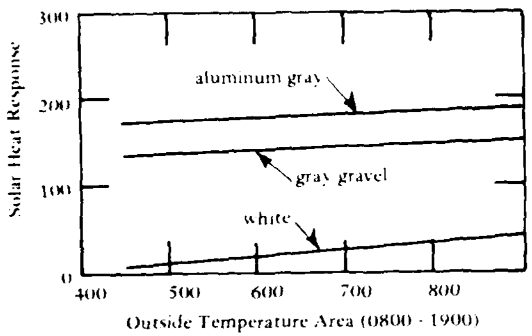
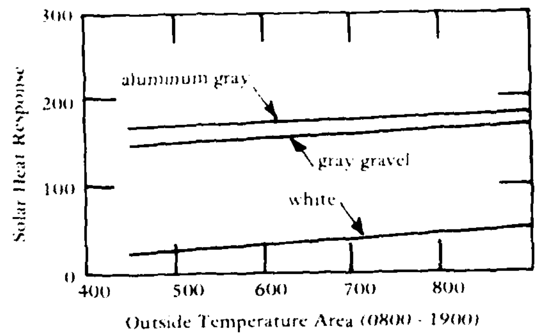


Figure 35. Aluminum gray surface temperatures in urethane/perlite built-up roof for December 7 - 8, 1978, ITCB No. 2.

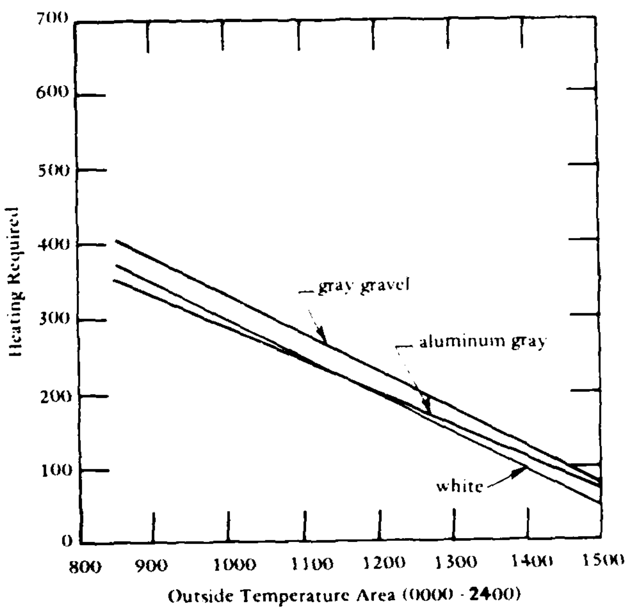


a. Over urethane.

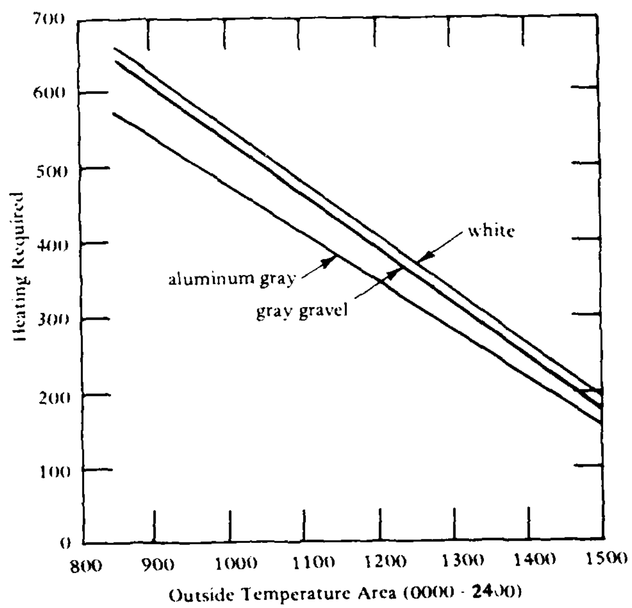


b. Over perlite.

Figure 36. Solar heat response in urethane/perlite built-up roof, ITCB No. 2, all surfaces, winter.

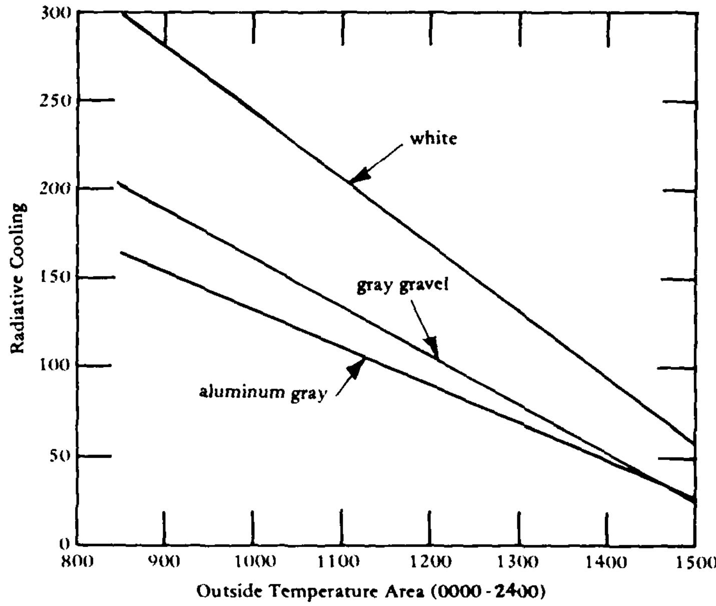


a. *Over urethane.*

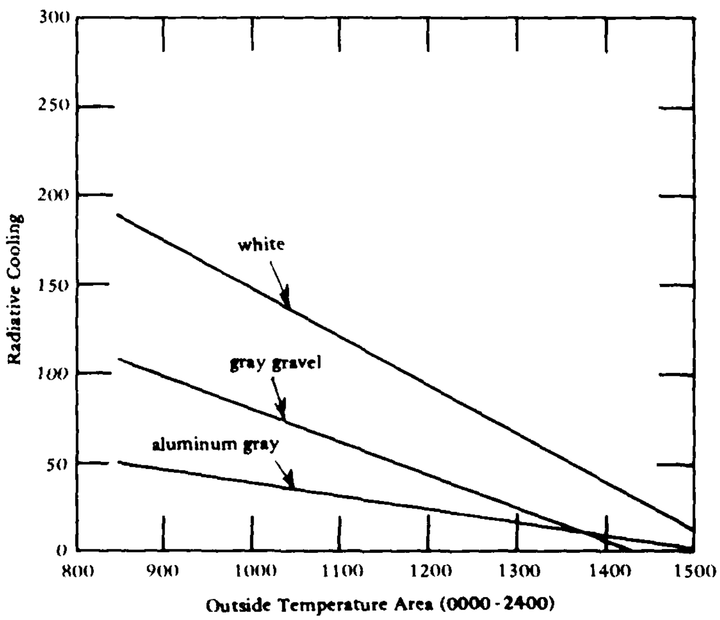


b. Over perlite.

Figure 37. Heating required in urethane/perlite built-up roof, all surfaces, ITCB No. 2, winter.

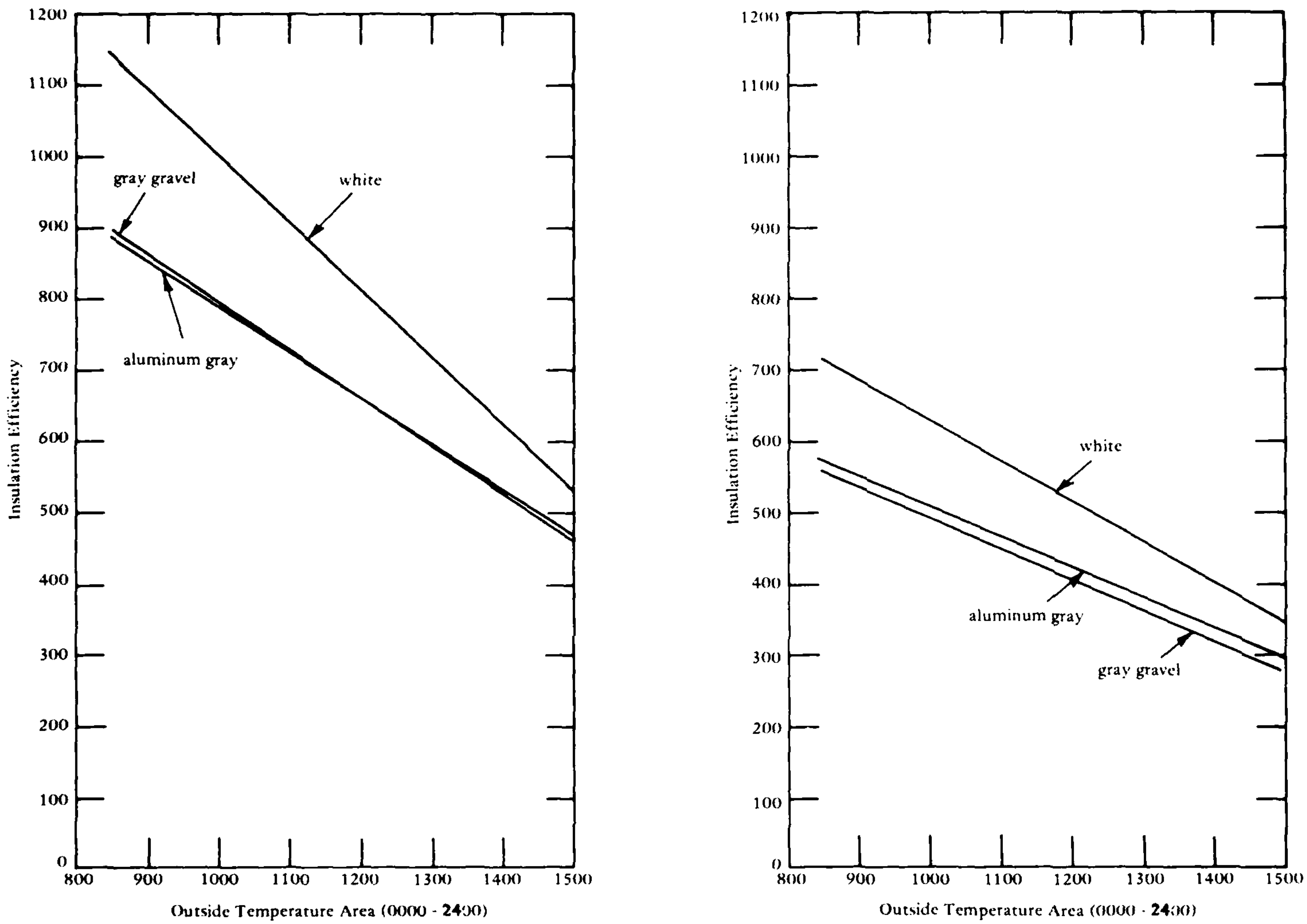


(a) Over urethane



(b) Over perlite

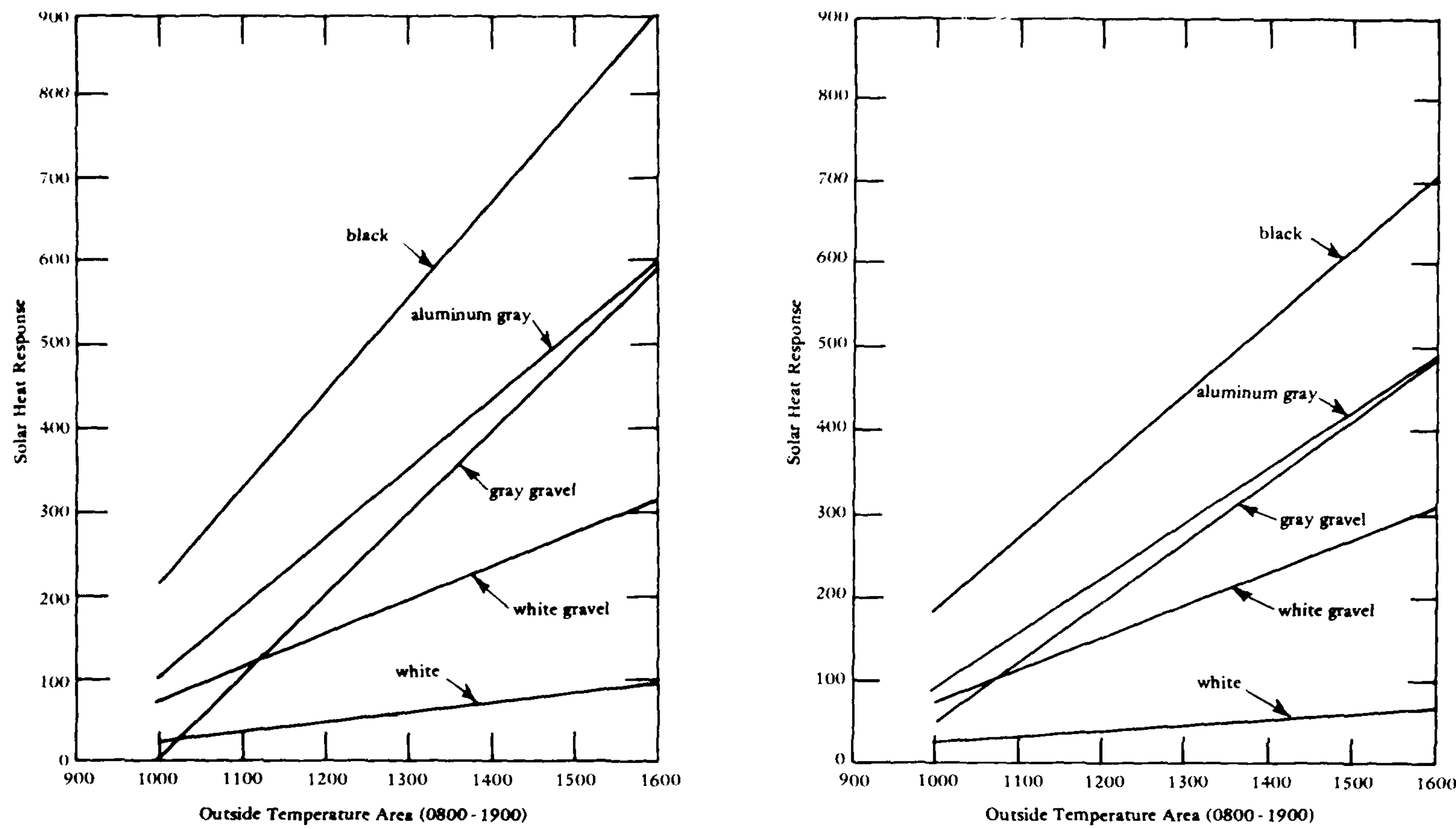
Figure 38. Radiative cooling in urethane/perlite built-up roofs, all surfaces, ITCB No. 2, winter.



a. Over urethane.

b. Over perlite.

Figure 39. Insulation efficiency in urethane/perlite built-up roofs, all surfaces, ITCB No. 2, winter.



(a) Over urethane.

(b) Over perlite.

Figure 40. Solar heat response in urethane/perlite built-up roof, all surfaces, ITCB No. 1 and No. 2, summer.

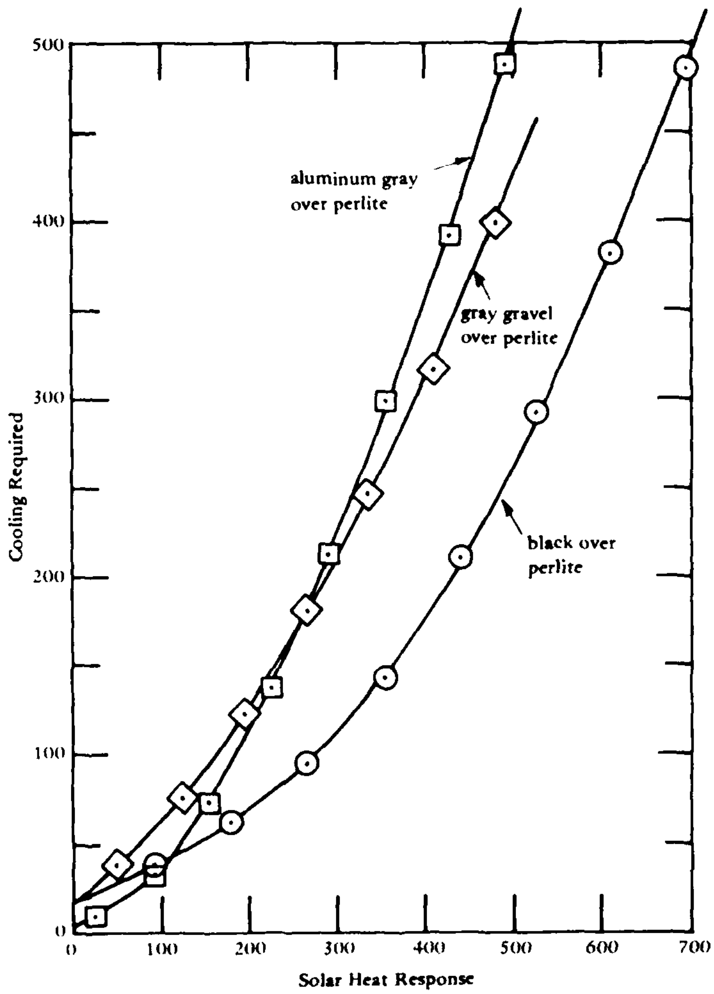
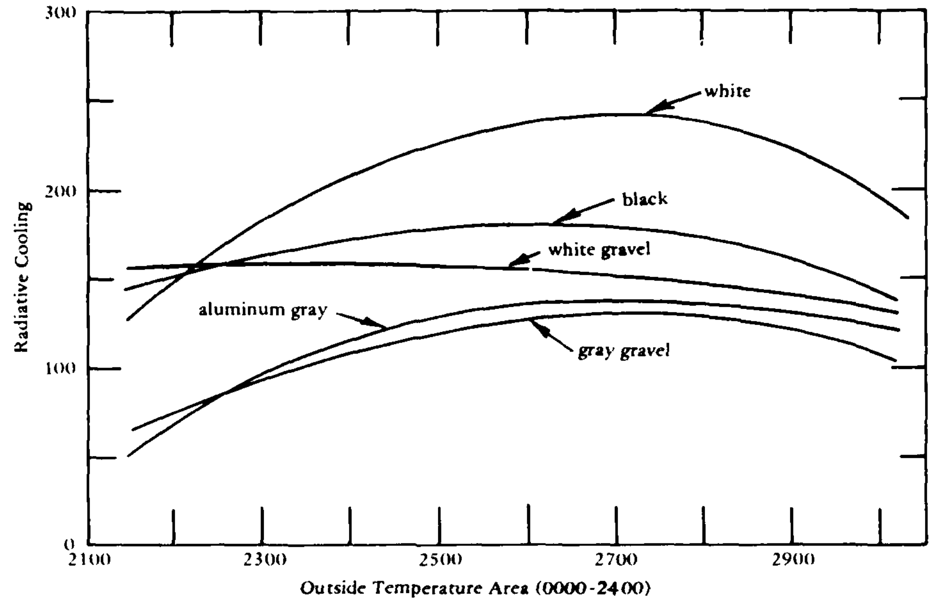
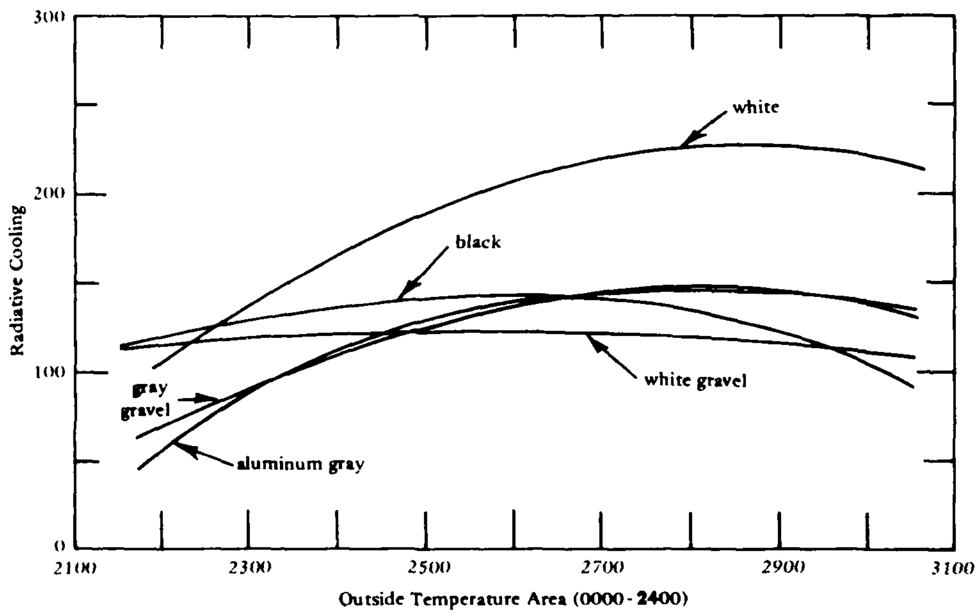


Figure 41. Relationships between solar heat response and cooling required in membrane over perlite, ITCB No. 1 and No. 2, summer.



(a) Over urethane.



(b) Over perlite.

Figure 42. Radiative cooling in urethane/perlite built-up roof, all surfaces, ITCB No. 1 and No. 2, summer.

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ONR Code 485 (Silva) Arlington, VA; Central Regional Office, Boston, MA; Code 221, Arlington VA; Code 700F Arlington VA; (Scientific Dir) Pasadena, CA
PHIBCB 1 P&E, San Diego, CA
PMTC Code 3331 (S. Opatowsky) Point Mugu, CA; Pat. Counsel, Point Mugu CA
PWC (Lt E.S. Agonoy) Pensacola, FL; ACE Office (LTJG St. Germain) Norfolk VA; CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; Code 10, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Code 120C, (Library) San Diego, CA; Code 128, Guam; Code 154, Great Lakes, IL; Code 200, Great Lakes IL; Code 200, Guam; Code 105 Oakland, CA; Code 220.1, Norfolk VA; Code 30C, San Diego, CA; Code 400, Great Lakes, IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Util Dept (R Pascua) Pearl Harbor, HI; Code 505A (H. Wheeler); Code 600, Great Lakes, IL; Code 601, Oakland, CA; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 700, San Diego, CA; LTJG J.L. McClaine, Yokosuka, Japan; Library, Subic Bay, R.P.; Utilities Officer, Guam
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